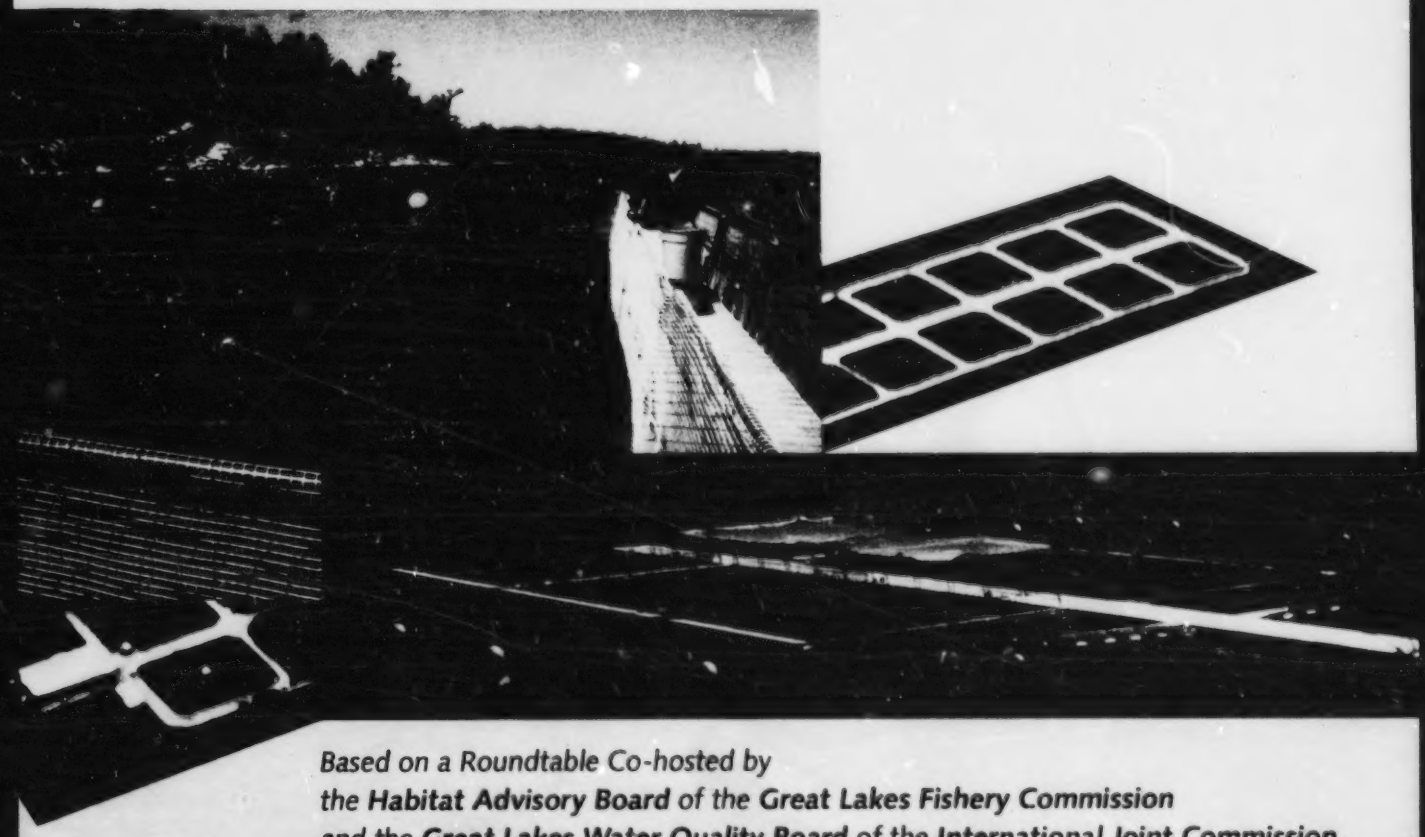
Addressing Concerns for Water Quality Impacts from Large-scale Great Lakes Aquaculture



Based on a Roundtable Co-hosted by
the ***Habitat Advisory Board*** *of the* ***Great Lakes Fishery Commission***
and the ***Great Lakes Water Quality Board*** *of the* ***International Joint Commission***

1999

Great Lakes Fishery Commission

Great Lakes Water Quality Board

Report to the International Joint Commission

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Addressing Concerns for Water Quality Impacts from Large-Scale Great Lakes Aquaculture

Based on a Roundtable
Co-hosted by the Habitat Advisory Board
of the Great Lakes Fishery Commission
and the Great Lakes Water Quality Board
of the International Joint Commission

Convened at University of Windsor's
Great Lakes Institute for Environmental Research
on January 27-28, 1999

Steering Committee members:

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This report is dedicated in memory of W.J. "Jack" Christie

Jack Christie spent his professional career as a fisheries research scientist for the Ontario Ministry of Natural Resources and was a long-time proponent of Great Lakes protection and rehabilitation. At the time of his death in 1997, he had just provided technical input to the Great Lakes Water Quality Board of the International Joint Commission and the Habitat Advisory Board of the Great Lakes Fishery Commission on expansion of Great Lakes aquaculture and concern for water quality impacts, introductions of exotic species, and loss of native gene pools. Jack cautioned that a sustainable strategy for aquaculture will require: consideration of all costs, from those at the local scale to those on the global scale; application of the lessons of history and the best science possible; and coordination and leadership among jurisdictions by the two Commissions. This report is dedicated in Jack Christie's memory and offered as a tribute to his contribution to ecosystem-based management of the Great Lakes.

Web Sites:

International Joint Commission
http://www.ijc.org

Great Lakes Water Quality Board of the International Joint Commission
http://www.ijc.org/boards/wqb/

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http://www.glfc.org/staff/hab.htm

Disclaimer:

The case studies presented in the appendices of this report do not necessarily represent the views or position of the author's associated organizations, the Habitat Advisory Board of the Great Lakes Fishery Commission, or the Great Lakes Water Quality Board of the International Joint Commission.

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PREFACE

The Food and Agriculture Organization of the United Nations defines aquaculture as the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Aquaculture began in the Great Lakes in the late 1800s, but experienced an increase in the number of operations in the 1980s. Currently, there are more than 1,000 Great Lakes aquaculturists.

There are several different types of aquaculture operations. The majority of Great Lakes operations are located on land. Land-based operations grow fish or other freshwater food products in ponds, tanks, or containers filled with water. Water quality impacts and permitting of land-based operations are generally more easily managed than in-water operations because the water from these operations is released at one point or pipe.

In-water operations consist primarily of net pens or cages. These nets are fashioned in the form of a large, floating bag which contains the fish, but allow water and waste to flow freely in and out. Currently, there are fewer than 15 caged aquaculture operations in the Great Lakes basin and numbers vary annually. All of these operations primarily raise rainbow trout for human consumption. Net pens or cages vary in size and production, but can have surface areas as large as 370 m^2 and can hold 100,000 fingerlings or 30,000 larger fish per cage. As well, many operations have several cages operating at any one time.

Aquaculture is openly promoted by several organizations and government agencies. Indeed, aquaculture provides a much needed alternative to depleting wild stocks of fish and other products. The industry also provides employment and spin-off economic benefits. However, aquaculture can become an issue when an operation has a negative impact on a public trust resource, the water body where it is located. Environmental problems have led to moratoria on the expansion of sites for salmon caged aquaculture operations in three of the world's largest producers of farmed salmon - Norway, Ireland, and Chile (Goldburg and Triplett 1997), and for a time in British Columbia, Canada. Some Great Lakes aquaculture operations, as seen in the case studies provided in this report, have impacted the resource as food waste and fish waste increased loadings of phosphorus and nitrogen leading to reduced water clarity and algal blooms. Fortunately, the majority of aquaculture operations have been properly sited and well managed to ensure a minimal water quality impact.

The future of aquaculture in the Great Lakes is difficult to project. Although the per capita consumption of seafood in the United States is not expected to increase, the demand for seafood is expected to increase in line with the increase in population. Site selection for aquaculture is limited by current available technology, as well as physicochemical suitability. U.S. and Canadian markets are sensitive to world markets affecting price and this, combined with the everyday difficulties associated with other forms of intensive agriculture such as disease, feed costs, weather, etc., will impact the economic viability of aquaculture.

The roundtable was held to encourage discussion of Great Lakes aquaculture, to provide a forum for objective and scientific evaluation of water quality impacts associated with fish and fish feed wastes and to encourage further investigations. However, this report only addresses water quality impacts of large-scale Great Lakes aquaculture. Other issues such as exotic species, disease transfer, use of therapeutics, etc. may be important and must be addressed in the future by management when considering growth and expansion of the industry. It appears the best documentation of water quality impacts comes from large-scale aquaculture operations; this report did not address issues and management concerns which may be unique to small fish farms operating within the Great Lakes watershed.

EXECUTIVE SUMMARY

Aquaculture is an emerging issue in the Great Lakes basin caused by an increased demand for freshwater fishes and by concern over expansion of a relatively new industry. Globally, the current demand for seafood has increased to the point where the United Nations estimates that nearly one-quarter of the protein in human diets is derived from seafood, of which 21% of the world consumption of seafood comes from aquaculture. With the rapid expansion of aquaculture there have been concerns expressed about the impacts the industry may have on water quality and biota, as well as economic and social benefits.

As part of the Great Lakes Fishery Commission charge to assess habitat alterations and recommend mitigative strategies to address concerns for aquaculture in the Great Lakes basin, a roundtable discussion of water quality impacts of Great Lakes aquaculture was held on January 27-28, 1999 in collaboration with the Great Lakes Water Quality Board of the International Joint Commission. This report only addresses water quality impacts of large-scale Great Lakes aquaculture. Water quality impacts due to hatchery operations have been documented in Michigan's Big Platte Lake (i.e., elevated phosphorus levels, increased primary productivity, reduced water transparency). In addition, water quality impacts due to caged aquaculture have been measured in Minnesota mine pit lakes (i.e., approximately an order of magnitude increase in water column phosphorus, nitrogen, and chlorophyll levels, and increased attached algal growth) and in one case in Ontario on the North Channel and Georgian Bay of Lake Huron (i.e., elevated phosphorus levels, reduced water transparency, algal blooms, and dissolved oxygen depletion over 250 ha). Industry representatives provided information that other operations in Georgian Bay have been well managed and have not resulted in any significant water quality problems. It was generally felt among roundtable participants that water quality problems can be substantially prevented with better assessment, siting, prediction of carrying capacity, and management of food and fish.

Caged aquaculture operations in the Great Lakes are currently limited by available technology and suitable sites. Neither caged nor land-based aquaculture is expected to grow substantially. The aquaculture industry is interested in achieving economically-viable and environmentally-sustainable operations. Both the aquaculture industry and governments want to limit water quality and habitat impacts.

One promising analytical tool, sponsored by the Great Lakes Fishery Commission, is being developed to help prevent water quality impacts from aquaculture and prevent introductions of exotic species. This decision support system titled "Environmental Assessment Tool for Private Aquaculture in the Great Lakes Basin" is being developed by the University of Minnesota. This user-friendly, computer-based system is designed to help direct impact assessments and guide risk management decisions regarding private aquaculture operations.

Based on a review of the information and discussions from the roundtable, and the extended abstracts presented in this report, the roundtable steering committee has made the following recommendations:

To governments it is recommended that:

- **better site assessments be performed as part of the application for all new caged aquaculture operations, including site specific prediction of carrying capacity (e.g., the University of Minnesota Environmental Assessment Tool could be field tested on new permit/ license applications);**
- **consideration be given to limiting caged aquaculture operations based on a feed quota with specified feed quality;**
- **a routine monitoring program be required as part of each caged aquaculture license or permit (e.g., benthic community structure, chemistry, periphyton, etc.); and**
- **best management practices be developed and implemented for all caged aquaculture operations (e.g., an aquaculture operation could be encouraged to obtain ISO 9000 and 14000 certification);**

To the Great Lakes Fishery Commission and the International Joint Commission it is recommended that they:

- **continue to track the issue of water quality impacts from Great Lakes aquaculture as a "watching brief"; and**
- **ensure that the related aquaculture issues of comprehensive disease management, introduction of exotic species, use of therapeutics, etc. be addressed in the future.**

To government agencies, universities, and the Commissions it is recommended that the following research needs be addressed:

- **the development and application of simple, rapid, bioassessment tools, biologically-based standards for unacceptable water quality and habitat impacts, and practical "early warning" indicators for signs of changing benthos, phytoplankton, and zooplankton;**
- **the development and application of models to estimate "carrying capacity" and predict site suitability for aquaculture operations;**
- **the frequency, extent, and feasibility of fallowing or resting a site required to minimize impacts;**
- **the nutrient/energy efficiencies of fish feed;**
- **the efficacy of alternative nutrient abatement technologies;**
- **the impacts of caged aquaculture operations on structure and function of the aquatic ecosystem; and**
- **the relative impact of existing land-based aquaculture operations.**

To the aquaculture industry it is recommended that:

- **caged aquaculture applicants assess the "carrying capacity" of the proposed site and allocate waste loadings within that capacity;**
- **adequate pre- and post-operational monitoring be conducted;**
- **efforts be made to involve early-on all stakeholders (e.g., cottage owners) in planning in order to gain acceptance and to identify and avoid problems;**
- **fish farmers consider using highly digestible, nutrient dense diets (for example those developed by the Ontario Ministry of Natural Resources and University of Guelph) which contain less phosphorus, are less polluting, and could prove cost-effective for fish production; and**
- **fish farmers consider developing an environmental management system under ISO 14000 which incorporates use of best available technologies and requires adequate monitoring for continuous improvement in operations.**

INTRODUCTION

Aquaculture is an emerging issue in the Great Lakes basin caused by an increased demand for freshwater fish and concern over expansion of a relatively new industry. Globally, the current demand for seafood has increased to the point where the United Nations estimates that nearly one-quarter of the protein in human diets is derived from seafood, of which 21% of the world consumption of seafood comes from aquaculture. With the rapid expansion of aquaculture there has been an increased concern for the impacts the industry might have on water quality and biota, as well as economic and social benefits. A specific concern has been poor monitoring and assessment of existing sites and poor predictive capability for the impacts of new sites.

An increasing interest in aquaculture development in the Great Lakes basin has prompted the Great Lakes Fishery Commission to sponsor development of a model management program for private aquaculture. Towards this goal, an aquaculture environmental assessment tool is being developed to be a user-friendly, interactive, window-based program that addresses lake-based, land-based, and secured aquaculture systems. This decision support system involves three interrelated components: the assessment of potential environmental effects; provision of scientific background; and when specific risks are identified, recommendations for risk management.

As part of the Great Lakes Fishery Commission efforts to address concerns for aquaculture in the Great Lakes basin, a roundtable discussion of water quality impacts of Great Lakes aquaculture was held on January 27-28, 1999 in collaboration with the Great Lakes Water Quality Board of the International Joint Commission.

The primary objectives of this roundtable were to:

- **review the state of knowledge of water quality impacts of existing aquaculture;**
- **share information;**
- **identify knowledge and information gaps; and**
- **provide management advice to both boards.**

Secondary objectives were to:

- **identify the known and potential long-term water quality impacts of Great Lakes aquaculture;**
- **gather information on the current water quality protection/safeguards and their effectiveness; and**

- **look at opportunities for prevention or abatement of water quality impacts due to aquaculture.**

This report summarizes the discussions of the roundtable, presents extended abstracts of talks presented at the roundtable, and provides management advice relative to the roundtable objectives.

ROUNDTABLE DESIGN AND PROGRAM

The roundtable was designed to share current experiences and perspectives relevant to aquaculture in the Great Lakes basin and to solicit management advice (Appendix 1). Approximately 50 people attended, including representatives from government, academia, industry, First Nations, and environmental nongovernmental organizations (Appendix 2).

The roundtable began with a series of background talks on aquaculture, familiarizing participants with the current situation in the Great Lakes. These background talks were followed by a series of case study presentations outlining aquaculture experiences and lessons from Ontario, Michigan, Minnesota, and British Columbia. At the end of day one, roundtable participants developed some key messages from the day and addressed the following questions:

- **What are the known water quality impacts of Great Lakes aquaculture?**
- **What are the potential long-term impacts?**

On day two, two breakout groups discussed and answered key questions regarding water quality impacts of Great Lakes aquaculture. The questions addressed included:

- **What can be done to prevent or abate water quality impacts due to aquaculture? Is there adequate protection under the current law? What are the various roles of government and industry?**
- **Can governments ensure "no net loss" of physical and chemical habitat from new Great Lakes cage cultures through impact predictions and modelling combined with licensing/permitting? If no, then what does the "precautionary approach" indicate for approvals/permitting?**
- **What are the priority research needs?**
- **What monitoring strategies are needed and are in place?**

Following the breakout sessions, participants reconvened in plenary to receive breakout session reports and develop some conclusions and recommendations.

SYNTHESIS OF ROUNDTABLE DISCUSSION AND KEY FINDINGS

Known Water Quality Impacts of Great Lakes Basin Aquaculture

Aquaculture operations will have some impact on the natural environment or an "ecological footprint." For this report, ecological footprint means the extent and severity of ecological impact caused by aquaculture operations. This concept of ecological footprint has been developed by Wackernagel and Rees (1996) to address carrying capacity (i.e., the corresponding area of productive land and aquatic ecosystems required to produce the resources used, and to assimilate the wastes produced by, a defined population at a specified material standard of living).

Major water quality problems due to aquaculture can and have included:

- **increased phosphorus and nitrogen over background levels;**
- **increased primary productivity (as measured by chlorophyll *a* and algal biomass);**
- **elevated total suspended solids and biochemical oxygen demand; and**
- **dissolved oxygen depletion.**

Roundtable participants noted that an aquaculture operation can become a problem when operators attempt to grow more fish than a given area and water volume can sustain (i.e., exceed the carrying capacity). In addition, there is degradation and loss of habitat.

Aquaculture operations in Minnesota, Ontario, and Michigan have resulted in water quality impacts (Table 1). In Minnesota (i.e., mine pit lakes), the water quality improved following cessation of aquaculture operations (Appendix 10). In Michigan (i.e., Big Platte Lake), water quality conditions have improved after making improvements in hatchery operations and reducing phosphorus loadings (Appendix 7). However, recovery has not yet been documented in LaCloche/North Channel, Ontario (Appendix 9). It was noted by industry participants that several operations in Georgian Bay have been well managed and have not resulted in any substantial water quality problems (Appendix 12). Participants noted that many water quality impacts can be prevented through better assessment, siting, prediction of carrying capacity, and management of aquaculture operations for example.

Table 1. Water quality problems attributed to selected aquaculture operations in Minnesota, Ontario, and Michigan

Characteristic or Concern	Minnesota	LaCloche/ North Channel (Ontario)	Big Platte Lake/River (Michigan)
Type of operation	Caged aquaculture	Caged aquaculture	Hatchery
Location	Inland mine pit lakes	North Channel and Georgian Bay on Lake Huron	Tributary to northeastern Lake Michigan
Species reared	Chinook salmon and rainbow trout	Rainbow trout	Coho and chinook salmon
Known water quality impacts	Exceedance of the NPDES* permit limit for phosphorus (33 µg/L); approximately an order of magnitude increase in water column phosphorus, nitrogen, and chlorophyll levels; increased attached algal growth	Exceedance of Provincial water quality objectives for phosphorus and dissolved oxygen; reduced water transparency; presence of algal blooms; dissolved oxygen depletion over 250 ha	Increased phosphorus loadings; elevated primary productivity; decreased water transparency; anecdotal reports of reductions in crayfish populations, emergent aquatic vegetation, and mayfly hatches

* National Pollutant Discharge Elimination System

Potential Long-term Impacts of Great Lakes Aquaculture

Based on a review of environmental effects of aquaculture in the U.S. by the Environmental Defense Fund, Goldburg and Triplett (1997) concluded that "when compared to the largest sources of nutrient pollution, such as municipal sewage systems, U.S. aquaculture operations have a relatively small impact on water quality." In 1998, there was an estimated production of 3,000 tonnes of rainbow trout in Georgian Bay (Lake Huron) which would have contributed an estimated 15 tonnes of phosphorus to Lake Huron that year (Appendix 9). This phosphorus loading would represent about 0.3% of the total phosphorus loading target to Lake Huron (4,360 tonnes). No lakewide effect would be expected, however, localized water quality impacts are possible.

Water quality impacts can be short- or long-term. Some degraded sites can recover relatively quickly (e.g., Minnesota mine pit lakes) where water quality improved following cessation of aquaculture operations (Appendix 10). In Michigan, water quality in Big Platte Lake did not substantially increase for approximately ten years after making improvements in hatchery operations and reducing phosphorus loadings (Appendix 7). Full recovery has not yet been documented in LaCloche/North Channel, Ontario (Appendix 9). Participants noted that many water quality impacts can be resolved through proper siting and management of aquaculture operations.

Participants noted that the long-term concerns for water quality impacts of aquaculture include short-term operational impacts and long-term impacts from accumulated nutrients, feces, and degraded habitat. A number of other potential issues were raised by participants. Limited information exists on many of these potential issues. Some participants felt that there is no evidence to suggest that there is any concern for some of these potential issues and that they should not be identified because they would be viewed by some individuals as actual problems. These potential issues raised at the roundtable, but not addressed either at the roundtable or in the report, include:

- **drug resistance - antibiotics for treating bacteria can potentially lead to increased bacterial resistance (Axler et al. 1996);**
- **disease magnification - an increase in the incidence and severity of diseases in wild populations of fish associated with highly concentrated aquaculture fish;**
- **impacts on fishery and biodiversity;**
- **disease transfer to wild populations of fish;**
- **water quantity conflicts; and**
- **incremental habitat loss.**

Some of these concerns have received considerable media attention outside the Great Lakes basin. They may not be relevant or applicable to the Great Lakes. Again, this report only addresses water quality impacts of large-scale Great Lakes aquaculture.

Prevention or Abatement of Water Quality Impacts

Overall, it was predicted that there will be more fish produced from caged aquaculture in the future, but probably not an order of magnitude increase in operations. Growth of land-based aquaculture is expected to be minimal due to higher costs for siting and often limited availability of suitable water quantities. Currently, there are an estimated 1,000 U.S. aquaculture producers in the Great Lakes (Appendix 5) and approximately 200 facilities in Ontario (Appendix 8). More accurate statistics on U.S. aquaculture will be available later in 1999 when the U.S. Department of Agriculture's first ever 1998 Census of Aquaculture will be completed (U.S. Department of Agriculture 1998). Globally the amount of seafood and freshwater fish consumed will increase due to an increase in population. For example, the U.S. population is expected to increase 1%. Although the 1997 U.S. per capita consumption of seafood has declined slightly to 6.6 kg (14.6 pounds) from 7 kg (15 pounds) in 1996, the total U.S. supply (landings plus imports) has remained relatively constant (Johnson 1998; Goldburg and Triplett 1997). Johnson (1998) attributes the consumption decline to supply constraint of some species and notes consumption increases in species such as salmon and catfish that are not supply constrained. Further to this, there has been a shift in consumption from wild-caught fish to aquaculture-raised fish due to depleting global wild stocks. These factors will contribute to a growing aquaculture industry.

Growth of the caged aquaculture industry in the Great Lakes is limited by the few remaining sites that are suitable using currently available technology. Key criteria for caged aquaculture site selection include a sheltered location, deep water, and good circulation.

Aquaculture within the Great Lakes is primarily limited to cage culture operations raising rainbow trout. This is primarily due to rainbow trout being more domesticated and having well established husbandry (Gord Cole, Personal Communication). Rainbow trout is a coldwater species and, as a result, the majority of aquaculture operations are located in northern areas of the Great Lakes such as Georgian Bay (Figure 1).

In Ontario, regulations state that 42 species of fish may be considered for aquaculture production (Appendix 8). Currently farming of warmwater species of fish such as walleye and yellow perch is limited by the economical viability, technology, husbandry information, and domestication necessary for farming species. In 1998, the University of Wisconsin System Aquaculture Institute in Milwaukee signed an agreement with the Red Lake Band of Chippewa Indians to study the potential of raising yellow perch at an aquaculture facility (University of Wisconsin Sea Grant 1998). The North Central Regional Aquaculture Center is also researching aquaculture production of several centrarchid species and lists the current potential for these species as moderate to high. Continued demand of high dollar value commercial fish and limitation of available coldwater sites may result in increased farming of warmwater species. Ocean cage technologies, that can be located further offshore, are not yet practical or economically feasible in the Great Lakes.

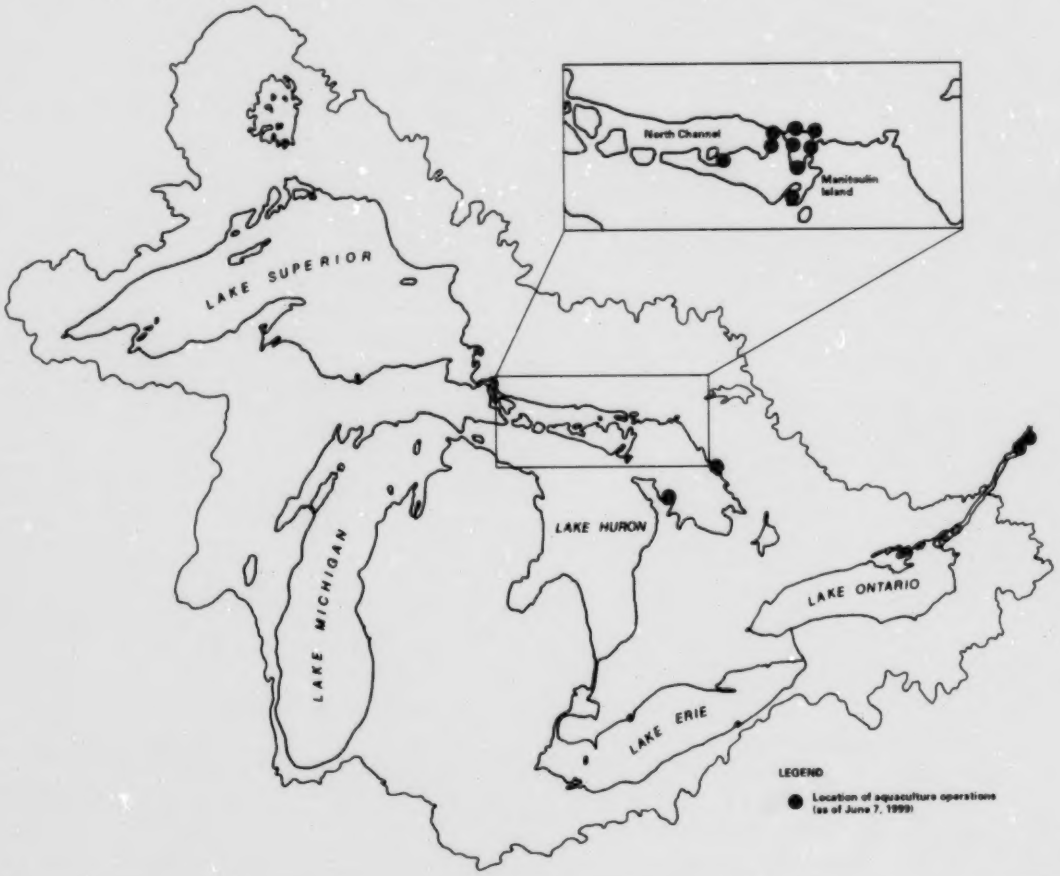

Figure 1. Great Lakes - St. Lawrence locator map displaying current, known, commercial cage aquaculture operations.

All aquaculture operations will have some impact or "ecological footprint." Concern was raised for how and who determines what changes in water and habitat quality are "unacceptable". There are currently no biologically-based, regulatory standards for making a determination of "unacceptable" water quality or habitat impacts. Therefore, there is a need for biologically-based regulatory standards for "unacceptable" water quality and habitat impacts that are applicable to aquaculture operations. Industry interests suggest that there must be a balance of economic, social-political, industrial, and administrative factors. It was suggested that any monitoring required in a permit/license should include an early warning capability (e.g., monitoring benthos or periphyton).

Prior to establishing an aquaculture farm, proper site assessments and adequate modelling are essential to determine where to locate operations. Site assessments must address "carrying capacity" and site-specific characteristics (e.g., shelter, water depth, circulation, sedimentation, morphometry). Better siting criteria can be built into modelling to predict site suitability. Size/scale must be taken into account, but putting restrictions on size/scale will limit business and the economy of scale. In British Columbia, all applications for finfish licenses and leases must follow specific siting and spacing criteria in relation to other operations, wild stocks, stream mouths, and critical habitat (Salmon Aquaculture Review 1997). Goldburg and Triplett (1997) agree stating that "siting net pens in areas with strong currents or tides that flush wastes and avoiding overly dense siting of net pens can help limit problems from waste accumulation."

The development of predictive models for the Great Lakes which consider current, feed rates, depth, bottom characteristics, flow velocity, ecological sensitivity, and other factors would be useful to predict the scale of operation a site can sustain. A site selection predictive model has been developed by the provincial Ministry of Agriculture, Fisheries and Food in British Columbia (Appendix 11). Proper siting would likely have prevented the establishment of an aquaculture operation in mine pit lakes in Minnesota. Mine pit lakes were not suited for aquaculture due to the relatively unnatural state of a very deep pit with little natural vegetation, no littoral zone, and low nutrients. The input of nutrients from overfeeding and fish waste resulted in a more intensive and immediate problem than other more natural sites.

One suggestion for managing impacts was to limit the size of aquaculture operations by establishing a feed quota with specified quality. For example, after a proper site assessment and prediction of size and scale of operations, a license/permit could be issued based on a given amount of food of a known phosphorus amount or establishing phosphorus quotas. The license/permit would also require monitoring. If monitoring during initial operations showed water quality problems, there would have to be an adjustment in the feed quota. If monitoring during initial operations showed no water quality problems, then operations could continue with the given feed quota.

Advances in the development of high nutrient dense, low phosphorus fish feeds have resulted in higher feed conversion rates and a decrease in fish waste (Cho and Bureau 1997; Appendix 4). The use of high nutrient dense diets for the production of rainbow trout is key to decreasing the amount of fish waste. Improvements in feeding strategies which result in higher consumption of feed and less waste of feed have also resulted in improved water quality and higher farm productivity.

Protection under current law

In Ontario, more than 12 agencies and 30 pieces of legislation potentially regulate aquaculture (Moccia and Bevan 1996). In general, roundtable participants felt that protection tools are available, but can be improved. In Ontario, aquaculture licensing is being addressed under the Fish and Wildlife Conservation Act, 1997 (proclaimed on January 1, 1999). The Canadian Federal Fisheries Act (Section 36) prohibits the deposit of deleterious substances into Canadian fisheries waters and the Act's definition of "deleterious" substance" can include organic waste, therapeutics, antifoulants, and pesticides. Participants felt that this vehicle is generally adequate if there are sufficient data and information available for the site. One suggested area of improvement would be to establish feed or production limits and a monitoring program in these licenses.

In the United States, National Pollutant Discharge Elimination System (NPDES) permits are used to regulate the industry. However, there is variability among the states because of differences in established numerical standards and designated uses (e.g., fish, recreation, etc.). Again, adequate data and information are essential for NPDES permits to be successful. A physicochemical and biological monitoring program should be a specific requirement in each permit. The U.S. Environmental Protection Agency (EPA) announced in February 1999 that the agency will be conducting a preliminary study of the aquaculture industry in order to gather information and determine whether national effluent guidelines will be developed for the aquaculture industry (U.S. Environmental Protection Agency 1998, 1999).

Roles and responsibilities of government and the aquaculture industry

Caged aquaculture systems differ from conventional land-based aquaculture facilities in the use of public trust resources as direct subsidy in the treatment of their wastes. Fish, wildlife, and navigable waters (including Great Lakes bottomlands) are common property of the people of the provinces and states that surround the Great Lakes. This common property right is one of the oldest public rights with roots from 13th Century English Law. Caged aquaculture operations do not have any means to treat their wastes and use Great Lakes bottomlands and aquatic biota to treat their wastes. It is very likely that the public will lose some of its established property rights and values as bottomlands decompose wastes. This will impair and decrease the fisheries value of the immediate area around the caged aquaculture operation. This loss of the public's property value from caged aquaculture wastes is a direct, but hidden, public subsidy to this industry. This is in direct contrast to land-based aquaculture facilities that are highly regulated and must use their own capital to treat their wastes prior to discharge to public trust waters of the provinces or states. As the trustee for the public's property, it is incumbent upon the provinces and states to be highly selective in allowing the use of caged aquaculture systems in Great Lakes waters and the public should be appropriately compensated for any loss of their property value.

To achieve economically-viable and environmentally-sustainable aquaculture there must be a shared responsibility between government and the aquaculture industry. All stakeholders should help design the rules and government should oversee enforcement. In practice, state and provincial governments have responsibility for fish management, including aquaculture. The industry wants reasonable government regulations to prevent water quality impacts from aquaculture.

Governments need to facilitate good management. For example, governments can develop processes that ensure a shared responsibility for adequate site assessments, monitoring, development of a phosphorus budget, and establishment of feed quotas. There also needs to be alternative dispute resolution mechanisms. For example, advisory committees have been successful in some states. Michigan experience has shown that aquaculture needs to stay out of the courts.

Most aquaculture operations in the Great Lakes are relatively small with limited resources. Government could fill a value-added role by sharing information on research and development, and by promoting technology transfer. One suggestion was to give governments authority and responsibility to ensure that "best management practices" are employed in all aquaculture operations.

It was suggested that the use of commercial equipment as per the recommendations of manufacturers should be encouraged. In addition, experienced and trained staff are required to carry out operations. In general, aquaculture facilities that are well sited and well managed to minimize environmental effects will be more sustainable in the long-term and will be more economically-viable.

Loss of habitat and the precautionary approach

In general, governments cannot ensure no loss of habitat from new Great Lakes caged aquaculture operations. There will undoubtedly be loss of physical, chemical, and biological habitat. There will be an ecological impact. However, this loss may be temporary if fallowing is practiced. Concern was raised for:

- **How long does it take for fallow (resting) sites to recover?**
- **Does this lead into cumulative impacts?**
- **Is site rotation a substitute for dilution?**

Such questions highlight the need to define what level of impact is acceptable. Before siting an aquaculture operation we must address "carrying capacity" and cumulative effects (e.g., via a wasteload allocation for phosphorus). Adequate monitoring will be a key to addressing loss and degradation of habitat. Industry representatives noted that any industry has environmental impacts, some of which are only temporary. Governments must make sure that any ecological impacts from caged aquaculture operations are temporary and confined. The practice of mandatory fallowing should be given consideration with the issuance of a permit/license.

Based on existing evidence, most governments cannot justify a moratorium on aquaculture operations due solely to the loss of habitat, but caution is warranted with respect to biochemical oxygen demand, total suspended solids, nitrogen, and phosphorus. What is needed is a reasonable and objective approach. Other issues raised which must be addressed within a precautionary approach include:

- **diseases;**
- **introduction of new species and strains; and**
- **use of therapeutics.**

Monitoring strategies

Monitoring is very important and an essential part of management. All historical data must be compiled and used to help establish a monitoring program. Where governments do not have the resources to monitor all lakes and operations, partnerships can be considered among government, industry, and citizen groups. Concern was raised regarding whether agencies will trust industry or citizen data. There will need to be standardization of monitoring protocols and analytical methods, along with good quality assurance and quality control. Governments must be willing to work with lake associations and industries.

One good example of a partnership is the aquaculture operation located in Manitowaning Bay on Georgian Bay in Ontario. Extensive water quality surveys were performed by industry to ensure the best possible water quality at the farm site.

There is a particular need to document critical habitats, such as fish spawning and nursery habitat, prior to siting. Any partnership for monitoring should address water quality, benthos, phytoplankton, structure and function of the fish community, and habitat requirements. Experience has shown that monitoring programs must be site specific and address both local and lakewide concerns. All data collected must be relevant and useful.

Research needs

A sound scientific knowledge base is essential to address issues related to Great Lakes aquaculture. We will probably never have a complete knowledge base and there will always be research needs. In 1994, the United States aquaculture industry received an estimated $60 million (U.S.) in financial assistance from the federal government, most of which was for research (Goldburg and Triplett 1997). Presented below are some research needs that participants felt should be addressed to help make decisions about siting aquaculture operations and proper management:

- **the development and application of simple, practical "early warning" indicators addressing detrimental changes to Great Lakes benthos, phytoplankton, and zooplankton;**
- **the development of best management practices for aquaculture operations, including risk-benefit analysis (perhaps the aquaculture industry could develop an environmental management system under ISO 14000);**
- **the development and application of simple models to estimate "carrying capacity" and predict site suitability for aquaculture operations;**
- **the development of "monitoring protocols" to provide adequate baseline and operational data;**

- **the frequency and extent of fallowing required to minimize impacts, as well as determining if it works in low circulation systems;**
- **the effectiveness of high conversion fish diets;**
- **the efficacy of alternative nutrient abatement technologies;**
- **the development of innovative waste removal technologies;**
- **the impacts of caged aquaculture operations on structure and function of the fishery and biodiversity; and**
- **comprehensive fish disease management.**

SUMMARY AND RECOMMENDATIONS

The January 27-28, 1999 roundtable discussion of water quality impacts of Great Lakes aquaculture raised awareness of a timely issue and facilitated discussion among representatives from government, academia, industry, First Nations, and environmental nongovernmental organizations (Appendix 2). Water quality impacts due to State hatchery operations have been documented in Michigan's Big Platte Lake (i.e., elevated phosphorus levels, increased primary productivity, reduced water transparency). In addition, water quality impacts due to caged aquaculture have been documented in Minnesota lakes (i.e., approximately an order of magnitude increase in water column phosphorus, nitrogen, and chlorophyll levels, and increased attached algal growth) and in one case in Ontario on the North Channel and Georgian Bay of Lake Huron (i.e., elevated phosphorus levels, reduced water transparency, algal blooms, and dissolved oxygen depletion over 250 ha). Industry representatives provided information that other operations in Georgian Bay have been well managed and have not resulted in any substantial water quality problems (Appendix 12). It was generally felt that water quality problems can be substantially prevented with better assessment, siting, prediction of carrying capacity, and management of food and fish.

Caged aquaculture operations in the Great Lakes are currently limited by available technology and suitable sites, and neither caged nor land-based aquaculture is expected to grow substantially. The aquaculture industry is interested in achieving economically-viable and environmentally-sustainable operations. Both the aquaculture industry and governments want to limit water quality and habitat impacts.

One promising analytical tool, sponsored by the Great Lakes Fishery Commission, is being developed to help prevent water quality impacts from aquaculture and prevent introductions of exotic species. This decision support system titled "Environmental Assessment Tool for Private Aquaculture in the Great Lakes Basin" is being developed by the University of Minnesota (Appendix 13). This user-friendly, computer-based system is designed to help direct impact assessments and guide risk management decisions regarding aquaculture operations.

Based on a review of the information and discussions from the roundtable, and the extended abstracts presented in this report, the roundtable steering committee has made the following recommendations:

To governments it is recommended that:

- **better site assessments be performed as part of the application for all new caged aquaculture operations, including site specific prediction of carrying capacity (e.g., the University of Minnesota Environmental Assessment Tool could be field tested on new permit/license applications);**

- **consideration be given to limiting caged aquaculture operations based on a feed quota with specified feed quality;**
- **a routine monitoring program be required as part of each caged aquaculture license or permit (e.g., benthic community structure, chemistry, periphyton, etc.); and**
- **best management practices be developed and implemented for all caged aquaculture operations (e.g., an aquaculture operation could be encouraged to obtain ISO 9000 and 14000 certification);**

To the Great Lakes Fishery Commission and the International Joint Commission it is recommended that they:

- **continue to track the issue of water quality impacts from Great Lakes aquaculture as a "watching brief"; and**
- **ensure that the related aquaculture issues of comprehensive disease management, introduction of exotic species, use of therapeutics, etc. be addressed in the future.**

To government agencies, universities, and the Commissions it is recommended that the following research needs be addressed:

- **the development and application of simple, rapid, bioassessment tools, biologically-based standards for unacceptable water quality and habitat impacts, and practical "early warning" indicators for signs of changing benthos, phytoplankton, and zooplankton;**
- **the development and application of models to estimate "carrying capacity" and predict site suitability for aquaculture operations;**
- **the frequency, extent, and feasibility of fallowing or resting a site required to minimize impacts;**
- **the nutrient/energy efficiencies of fish feed;**
- **the efficacy of alternative nutrient abatement technologies;**
- **the impacts of caged aquaculture operations on structure and function of the aquatic ecosystem; and**
- **the relative impact of existing land-based aquaculture operations.**

To the aquaculture industry it is recommended that:

- **caged culture aquaculture applicants assess the "carrying capacity" of the proposed site and allocate waste loadings within that capacity;**
- **adequate pre- and post-operational monitoring be conducted;**
- **efforts be made to involve early-on all stakeholders (e.g., cottage owners) in planning in order to gain acceptance and to identify and avoid problems;**

- **fish farmers consider using highly digestible, nutrient dense diets (for example those developed by the Ontario Ministry of Natural Resources and University of Guelph) which contain less phosphorus, are less polluting, and could prove cost-effective for fish production; and**
- **fish farmers consider developing an environmental management system under ISO 14000 which incorporates use of best available technologies and requires adequate monitoring for continuous improvement in operations.**

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Appendix 1

Roundtable Agenda

Roundtable on Water Quality Impacts of Great Lakes Aquaculture

Co-hosted by the Great Lakes Fishery Commission's Habitat Advisory Board and the International Joint Commission's Water Quality Board

University of Windsor's Great Lakes Institute for Environmental Research

January 27-28, 1999

AGENDA

Day 1	Wednesday, January 27
10:00 a.m.	**Welcome and Introductions, House Keeping** Doug Dodge, Great Lakes Fishery Commission's Habitat Advisory Board, John Hartig, International Joint Commission's Water Quality Board, Hugh MacIsaac, Great Lakes Institute for Environmental Research
10:10 a.m.	**Great Lakes Aquaculture and Water Quality** Ian Smith, Ontario Ministry of Environment
10:20 a.m.	**Aquaculture Waste and Feeding** C. Young Cho, University of Guelph
10:40 a.m.	**Expected Growth of Aquaculture - U.S. Experiences** Don Garling, Michigan State University
11:00	**Expected Growth of Aquaculture - Ontario Experiences** Ken Linington, Ontario Ministry of Agriculture, Food & Rural Affairs
11:20	**Michigan Experiences and Lessons - Platte River Hatchery** Gary Whelan, Michigan Department of Natural Resources
Noon	Lunch The Aquaculture Protocol model was demonstrated by Deborah Brister, University of Minnesota.
1:00 p.m.	**Ontario Experiences and Lessons** Al Sippel, Ontario Ministry of Natural Resources Steve Naylor, Ontario Ministry of Agriculture, Food & Rural Affairs
1:45 p.m.	**LaCloche/North Channel Case Study** Peggy Gale, Ontario Ministry of Environment

2:30 p.m. Coffee break

2:45 p.m. **Minnesota Experiences and Lessons**
Marvin Hora, Minnesota Department of Pollution Control

3:30 p.m. **British Columbia Experiences**
Al Castledine, B.C. Ministry of Fisheries

4:15 p.m. **Connections-Key Messages, Issues and Common Themes from Day 1**

- What are the known water quality impacts of Great Lakes aquaculture?
- What are the potential long-term impacts?

Charge for Day 2

Facilitated by Doug Dodge, Great Lakes Fishery Commission's Habitat Advisory Board

5:00 p.m. Adjourn for Day 1

Day 2 Thursday, January 28

8:00 a.m. **Facilitated Discussion of Key Questions in Two Breakout Groups**

(Candidate List) :

- What can be done to prevent or abate water quality impacts due to aquaculture? Is there adequate protection under the current law? What are the various roles of government and industry?
- Can governments ensure "no net loss" of physical and chemical habitat from new Great Lakes cage cultures through impact predictions and modeling combined with licensing/permitting? If no, then what does the "precautionary approach" indicate for approvals/permitting?
- What are the priority research needs?
- What monitoring strategies are needed and are in place?

(Facilitators: Ian Smith, Ontario Ministry of Environment and Doug Dodge, Great Lakes Fishery Commission's Habitat Advisory Board)

10:00 a.m. Coffee Break

10:15 a.m. Facilitated Discussion Continued

11:00 a.m. Reporting from both Breakout Sessions, Agreement on Take Home Messages, and Advice to Great Lakes Fishery Commission's Habitat Advisory Board and International Joint Commission's Water Quality Board

Next Steps - Report Production and Presentation (time frame)

Noon Adjourn

Appendix 2

Roundtable Attendees

Andrew Aryee, Fisheries and Oceans Canada

Bob Baldwin, Michigan Aquaculture Association

Fred Binkowski, Great Lakes WATER Institute

Gary Boersen, Michigan Department of Environmental Quality

Jim Boraski, Ontario Commercial Fisheries' Association

Anne Borgmann, Environment Canada, Environmental Protection Branch

Deborah Brister, University of Minnesota

Al Castledine, British Columbia Ministry of Fisheries

C. Young Cho, Ontario Ministry of Natural Resources and University of Guelph

Gord Cole, Ontario Aquaculture Association, Wasauksing First Nation, Aqua-Cage Fisheries

Mark Coscarelli, Michigan Department of Environmental Quality, Office of the Great Lakes

Lois Deacon, Ontario Ministry of Natural Resources

Marg Dochoda, Great Lakes Fishery Commission, Habitat Advisory Board

Doug Dodge, Ontario Ministry of Natural Resources, Habitat Advisory Board & Great Lakes Water Quality Board

David Dolan, International Joint Commission, Council of Great Lakes Research Managers

Peggy Gale, Ontario Ministry of Environment

Don Garling, Michigan State University

Rebecca Goldburg, Environmental Defense Fund

Bonnie Goodweiler, Wisconsin Department of Natural Resources

John Hartig, International Joint Commission, Great Lakes Water Quality Board

Thom Heiman, Department of Fisheries & Oceans

Marvin Hora, State of Minnesota - Pollution Control Agency

Rodney W. Horner, Illinois Department of Natural Resources

Phil Hulbert, New York Department of Environmental Conservation

Anne Kapuscinski, University of Minnesota

Val Klump, University of Wisconsin-Milwaukee, Council of Great Lakes Research Managers

Todd Leadley, Great Lakes Institute for Environmental Research, University of Windsor

Ken Linington, Ontario Ministry of Agriculture, Food & Rural Affairs

Hugh MacIsaac, Great Lakes Institute for Environmental Research, University of Windsor

Percy Magee, U.S. Dept. of Agriculture, Natural Resource Cons. Service, Great Lakes Water Quality Board

Lisa Maynard, International Joint Commission

G. Tracy Mehan, III, Michigan Dept. of Environmental Quality, Great Lakes Water Quality Board

Phyllis Miller, Ontario Ministry of Environment

Steve Naylor, Ontario Ministry of Agriculture, Food & Rural Affairs

Sandra Orsatti, Ontario Ministry of Natural Resources

David Reid, Ontario Ministry of Natural Resources

Al Sippel, Ontario Ministry of Natural Resources

Ian Smith, Ontario Ministry of Environment, Habitat Advisory Board

Lisa Tulen, International Joint Commission

David Walker, Ontario Aquaculture Association

Gary Whelan, Michigan Department of Natural Resources

Appendix 3

Great Lakes Aquaculture and Water Quality

by Ian Smith[1]

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What are the issues?

The Habitat Advisory Board of the Great Lakes Fishery Commission and the Great Lakes Water Quality Board of the International Joint Commission have jointly organized this roundtable to review the issue of aquaculture in the Great Lakes with respect to water quality and quantity. The Boards have an advisory role on ecosystem quality which they exercise by offering advice to governments and stakeholders alike. The potential impacts of cage culture and shore-based aquaculture in the Great Lakes basin upon physical, chemical, and biological attributes of aquatic habitat and ecosystem health are what drew the Boards to consider this issue. During the organization of the roundtable it became clear that the issues surrounding cage culture were particularly complex. Some of the issues for cage culture were similar to those for land-based operations, but others were unique, largely because of the physical setting that typically characterizes cage cultures.

The question of whether cage culture is a sustainable industry without environmental impacts has been asked in many regions. Controversy abounds on two salt-water coasts with respect to economic viability and habitat impacts – in the Great Lakes, water quality impacts have recently emerged as a consideration. Representations by industry representatives suggest that behind the hype of interest groups and controversy surrounding how governments regulate and manage this industry exists a willingness of the industry to ensure that negative impacts are minimized. This roundtable was organized to provide the two boards access to the experts from both sides of the issue so that recommendations to their parent organizations can be made. An additional consideration was to offer a forum where experts from both sides of the border (and issue) could share insights and possibly solutions.

When traditional hatchery and aquaculture facilities are sited on land, the impacts on aquatic habitat, water quality and water quantity are relatively simple to assess and manage. Nutrient impacts on receiving water quality, groundwater drawdowns that reflect unsustainable withdrawals, and observation of escaped fish all represent measurable impacts that can be man-

[1] This article was prepared on behalf of the Habitat Advisory Board of the Great Lakes Fishery Commission, and does not represent the perspective or position of the Ontario Ministry of the Environment.

aged simply. What makes the issues surrounding cage cultures so much more complex is the more "open" environment in which they operate. The waters where cage operations are typically placed are large, open and deep, making nutrient impacts difficult to monitor without expensive equipment or surveys. How much water a cage culture "takes" is unknown, but the production of fish/year can be used as a measure of "water use" and hence a means of comparison. Escaped fish from cages is typically the most easily observed impact, characterized by fleets of fishing boats drawn up next to the border delineating the operation.

The challenge for the governments and industry in ensuring the cage culture industry is economically-viable and environmentally-sustainable comes from the peculiar nature of the operation itself. The waters of the Great Lakes are "public" and hence cages are using a "common resource" for fish production. The issues around siting cages, cage design, location of shore facilities, etc. can become significant public issues during consultation prior to licensing. The limits on the growth of traditional land-based units caused by land prices and taxation, or restrictions on water extraction and discharges for example, make the development of cage culture operations a potential area of growth, which could exacerbate public concerns, and which will challenge the governments licensing and permitting such facilities. The existence of land-based aquaculture may be complicated in the future by the increased pressure upon both groundwater and surface water supplies. Global warming, El Nino and other causes for water shortages will undoubtably put pressure upon the use of water to grow fish. Applications for permission to grow new species of fish represent an additional area of consideration for regulators, given the "open" nature of the Great Lakes basin and the demonstration of exotic species impacts virtually ad-nauseam in the past.

What is the workshop answering?

The plethora of positions and issues has led the two boards to construct this roundtable in such a way as to answer, if possible, the following questions, with a view towards identifying the most significant issues which should be raised with the Great Lakes governments and other interested parties:

1) What are the known water quality impacts of Great Lakes aquaculture? What are the potential long-term impacts?

Known impacts include chemical (habitat) impacts on productivity of receiving waters (eutrophication) resulting in enhanced biological productivity and occasionally reduced dissolved oxygen. Solids discharged from the facilities can foul adjacent physical habitat and reduce oxygen content. Water clarity can be reduced and the occasional dead fish can produce a disagreeable aesthetic situation. Over the longer term, impacts on ecosystem health of introduced species that escape, disease introduction and exacerbation, and the development of antibiotic resistant disease organisms are potential biological concerns. On the water quantity side, groundwater supplies and multiple use for increasingly scarce surface water supplies are likely areas of conflict. User conflicts over the allocation of sites for cage cultures, given the common nature of the affected resource, are not a "quality" issue, but will continue to focus public scrutiny on the cage culture industry.

2) What can be done to prevent or abate water quality impacts due to aquaculture? Is there adequate protection under the current law? What are the various roles of government and industry?

Land-based aquaculture facilities typically have to meet regulations or rules for their discharge so that negative impacts are minimized. Given the ease in monitoring these facilities and their impacts, such protection is likely to be adequate for water quality, but may have to be re-evaluated with respect to water quantity if water shortages and a reduced water budget in the Great Lakes basin becomes issues. Regulations or rules can specify discharge limits as a simple means of limiting negative impacts. For cage culture facilities, the siting and design of facilities, and their management, are ways of minimizing water quality impacts, including practices such as cage rotation, variable feeding regimes, or low density rearing. The principle concern for governments, in pursuit of their mandate to ensure impacts are minimized, is that they do not traditionally have the legal ability to mandate "husbandry" practices, but can only manage "discharges". Ensuring that adequate protection is maintained must clearly make a link between husbandry and "discharges" through either monitoring or modeling. The industry and the governments both have a role in ensuring impacts are minimized, one through creative husbandry and the other through flexible rules and regulations.

3) Can governments (or the industry) ensure "no net loss" of physical and chemical habitat from new Great Lakes cage cultures? What does the "precautionary approach" mean for the industry?

It is generally accepted that incremental habitat (physical, chemical, and biological) loss represents a real threat to the health of the Great Lakes aquatic ecosystem. The real gap in knowledge to predict the impacts of seemingly minor habitat alterations upon productivity, diversity, adaptability, and even location of native fauna remains a singularly troubling phenomenon. One way to counter this absence of predictiveness is to "try it" and monitor changes, fine-tuning facilities and practices until no detectable impact is perceived. This approach however is costly in requiring regular monitoring and that the farm manager must be responsive to making changes so as to eliminate demonstrated impacts. Another is to develop and fine-tune predictive models that can be calibrated to consider current, feed rates, depths, bottom characteristics, ecosystem sensitivity, and other factors so that less intensive monitoring is necessary. Another consideration is the use of the "precautionary" approach, suggesting that in the absence of robust science, an extremely cautious approach to developing new facilities and changing husbandry or production at existing facilities be taken. The introduction of new species and management of diseased populations are two areas with potentially profound long-term impacts where the precautionary approach may be prudent. Physical and chemical impacts from feed and feces are areas where a more iterative approach may be useful.

4) What are the priority research needs?

Governments are typically a significant contributor of the science to support management and hence the economic viability and sustainability of the resource being developed. In the case of the Great Lakes much can be learned from the experiences and research undertaken to support coastal cage operations in salt water. Areas that may be valid for research include the threat to wild fish posed by disease infecting caged or land-based operations, and the proper and prudent use of antibiotics to ensure disease resistence is not promoted. Modeling to facilitate siting and licensing seems a reasonable area for research, in order to predict impacts before they must be demonstrated if the iterative approach to siting is chosen. Given that the precautionary approach would suggest limiting new development until better certainty is obtained, the development of predictive Great Lakes models based upon monitoring and analysis of existing facilities would seem an area where the industry can offer support and cooperation, so that the onus does not rest solely upon the Governments.

5) What monitoring strategies are needed and are in place?

Just what is the appropriate and necessary level of monitoring for aquaculture operations? Existing facilities may be grandfathered with respect to their operations, but given the interest in incremental loss and increasing pressure upon the aquatic resource, monitoring and compilation of the results of this monitoring in support of modeling would appear reasonable. For a new facility, whether cage or land-based, intensive monitoring until the facility becomes established and the ecosystem is in balance would also appear reasonable. But what to monitor, how often, and by who are the questions often asked. As stream beds and lake beds in the Great Lakes basin are normally a common resource, is there any onus on "the people" to ensure ecosystem health is regularly assessed? If the operator bears the entire responsibility, how is the monitoring undertaken, by agreement or by law? Is their sufficient food safety inspection procedures in place, as well as disease surveillance monitoring taking place? How is the level of escapement tracked and assessed? Finally, how accessible to the public and interested stakeholders is the monitoring information, particularly where a public and common resource is being assessed and possibly affected? Can the industry and/or governments provide a report card on the status of the environment upon which the industry is based?

What happens next?

The workshop summary will include the perspective and response of the attendees to the above noted questions. The two boards will review the workshop outcome and make recommendations to their parent agencies as they deem appropriate. Both boards are interested in the existing and potential water quality impacts of land-based and cage culture operations including nutrients and solids, and in the considerations being given to water (groundwater) use and quantity by land-based facilities, but they are most interested in the ability of the industry and the governments to manage aquaculture in a sustainable manner. It is likely that the governance of the industry by all levels of government, and the role of farm managers and industry associations, will receive the bulk of the boards attention. Both boards note with interest the operation of cage cultures by Tribes and First Nations, and the special challenges posed in this area of governance.

As the full impacts of reduced nutrient loadings to the open waters of the Great Lakes become visible through reduced wild fish production, due to successful management of farming practices and detergents, and the altered availability of primary productivity resulting from zebra mussel invasions, aquaculture has the potential to replace the traditional net fishery in supplying protein. However, it cannot do so at the expense of the health of the aquatic environment. In this context it is likely that the boards will request of the governments that some "common floor" in the area of policy and implementation be established in their oversight of this industry, given that the Great Lakes are a precious and shared resource, and that water quality and quantity are essential for the sustainability of the aquaculture industry.

Appendix 4

Nutritional Strategies for the Management of Aquaculture Wastes

by Dominique P. Bureau and C. Young Cho

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Introduction

There is a growing consensus about the need to reduce waste production in aquaculture to minimize the negative impacts on the environment, comply with legislation and limit self-pollution. For many years now the Fish Nutrition Research Laboratory (OMNR/University of Guelph) has been at the forefront of the development of nutritional strategies for the management of aquaculture waste output and has organized three international symposia on the topic. Three types of strategies have been used by our laboratory and OMNR fish culture stations for the management of aquaculture waste output, namely feed formulation, feed requirement prediction models, and biological approaches to waste output estimation.

Feed Formulation

Fundamental to waste management strategy is a reduction of waste at the source, namely the diet. Pollution problems are often related to undigested carbohydrate, nitrogen, and phosphorus levels in effluent which stimulate eutrophication. Protein and lipid are, in general, well digested by fish and represent a minor component of solid waste. However, nitrogen excretion resulting from dietary protein oxidation is a major component of dissolved waste. Optimizing the protein/energy ratio in diets reduces nitrogen excretion. Application of the above principles has led to the development of high nutrient dense (HND) diets which are both highly digestible and nutrient/energy dense. The basic principles used in formulating HND diets are neither new nor complicated. Firstly, very digestible ingredients with low phosphorus to nitrogen ratio should be selected for feed formulation. Secondly, nutrients (mainly nitrogen and phosphorus) in the diet must be well balanced as to optimize their utilization by the animal and hence reduce dissolved waste outputs. Simply stated, the approach is to exclude poorly digested, low energy and low protein ingredients, such as grain by-products rich in starch and fiber, and to reduce reliance on high ash fish meals as protein sources. HND diets, high in both protein and fat while maintaining a protein to energy ratio of 20-22 g digestible protein/MJ digestible energy (84-92 g/Mcal) and a digestible energy level around 20 MJ (4.8 Mcal), are very desirable for effective management of waste reduction at the source.

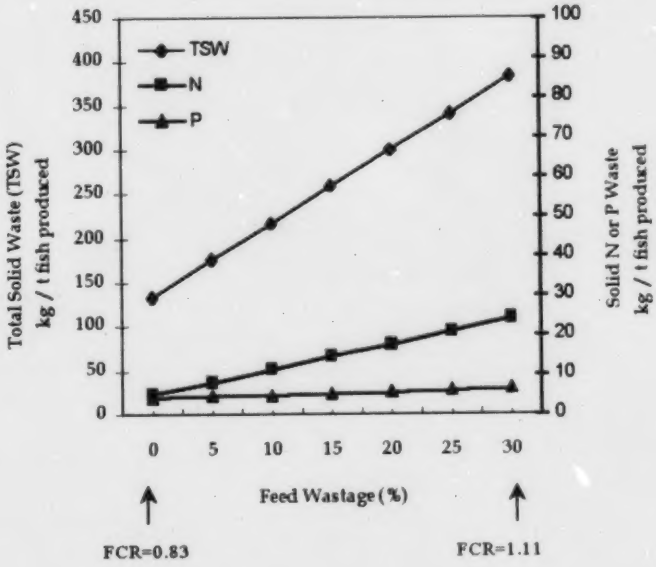
Figure 1 illustrates the importance of minimizing feed waste from an environmental point of view. Only a small proportion (approximately 15-25%) of a given amount of feed consumed by a fish will be excreted as solid waste. Feed that is not consumed by the animal, on another hand, will become 100% solid and suspended wastes. Figure 1 shows that as feed wastage increases from 0% to 30% (in this example when feed conversion ratio (FCR) (feed/gain) of 1.11:1 is obtained instead of 0.83:1), solid nitrogen waste outputs by the fish quadruples, total solid waste triples, and solid phosphorus waste is increased by about 60%. On top of these solid wastes add the dissolved wastes produced by the fish and this results in substantial, yet partly avoidable, waste loads.

Feed wastage depends mostly on feeding practices used and little on the feed itself. Most of the feeding charts available today are "desktop" modifications of feeding guides originally developed with semi-moist meat/dry meal based diets of the past. One must be cautious in applying these charts to modern diets which have higher energy and nutrient densities. Ultimately the animal itself should determine the quantity of energy and nutrients appropriate to satisfy its requirements, but this is often impossible. The scientific estimation of feed allowance and careful feeding of the fish may be the only sensible approaches to ensure environmentally- and economically-sustainable aquaculture production.

Figure 1. Effect of Feed Wastage on Solid Waste

Feed: 44% Digestible Protein (DP), 20 MJ/kg Digestible Energy (DE), DP/DE = 22 g/MJ, 7.6% Nitrogen (N), 1% Phosphorus (P)

Rainbow trout growing from 10 to 100g in 410 days, water temperature 0.5 to 20°C



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Sufficient data on nutritional energetics are now available to allow reasonably accurate feeding standards to be computed for different aquaculture conditions. Bioenergetic models were developed by our laboratory and a stand-alone multimedia program (Fish-PrFEQ) is being developed to facilitate computation of the models. This program predicts growth and energy, nitrogen and phosphorus retention, requirements and excretions to determine feeding standards, waste outputs, and effluent water quality.

Regardless of the feeding system or method used, accurate growth and feed requirement models can be very valuable management tools since they may allow us to forecast growth and objectively determine biologically achievable feed efficiency (based on feed composition, fish growth, composition of the growth). These estimates can be used as yardsticks to adjust feeding practices or equipment, compare results obtained, and help improve husbandry practices.

Estimating Waste Output

Directly monitoring and estimating waste in effluent is often an inaccurate and costly process. Biological Methods for the Prediction of Aquaculture Waste Outputs (BMPAWO) have been developed as simple and economical alternatives to limnological/chemical methods of estimating waste outputs. Waste output loading from aquaculture operations can be estimated using simple principles of nutrition. Ingested feedstuffs must be digested prior to utilization by the fish and the digested protein, lipid, and carbohydrate are the potentially available energy and nutrients for maintenance, growth, and reproduction of the animal. The remainder of the feed (undigested) is excreted in the feces as solid waste (SW), and the by-products of metabolism (ammonia, urea, phosphate, carbon dioxide, etc.) are excreted as dissolved wastes (DW) mostly by the gills and kidneys. The total aquaculture wastes (TW) associated with feeding and production are made up of SW and DW, together with apparent feed waste (AFW). Since direct estimation of AFW is almost impossible, best estimate can only be obtained by comparison with theoretical feed requirement calculated with bioenergetic models.

In summary, the nutritional strategies for the management of aquaculture waste (NSMAW) are the best approach to reduce the waste output from the source for sustainable aquaculture:

1. DIET selection
2. GROWTH prediction
3. WASTE estimation
4. RATION allowance
5. FEEDING strategies.

Comparative studies conducted in a number of fish culture stations have shown that BMPAWO are less expensive and yield more realistic and consistent results than chemical/limnological methods based on continuous sampling of the effluent. BMPAWO are also more flexible since waste outputs can be estimated in advance as well as for culture conditions where it would be very difficult to estimate waste outputs using limnological methods (e.g., cage culture).

Information on the procedures and models discussed here, the Fish-PrFEQ program and the three international symposia, as well as a list of references, can be obtained from our website www.uoguelph.ca/fishnutrition.

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Appendix 5

Status and Expected Growth of Aquaculture - U.S. Experiences

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Introduction

Food and Agricultural Organization (FAO) of the United Nations defines aquaculture as the farming of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated (FAO 1996) which distinguishes aquaculture from the harvest fishery.

The worldwide production of aquatic organisms from all sources has increased from 95.6 million tonnes in 1987 to 121.0 million tonnes in 1996 (H.M. Johnson and Associates 1998). Over this ten-year period, an increasing proportion of this global production is being supplied by the private sector aquaculture community. In 1996, the last year for which there is published data, almost 22% of the total aquatic production, 26.4 million tonnes, was supplied by aquaculture. This represents almost a 150% increase (2.5 times) over the 1987 production level of 10.6 million tonnes. The United States is a relatively minor player in the context of world aquaculture production, accounting for a little less than 2% of the total tonnage, and ranking only tenth in the world in terms of economic value of its aquaculture products in 1994 (FAO 1996).

United States Overview

Even though minor in a global context, U.S. aquaculture is still an important primary industry, creating approximately 181,000 jobs nationwide and generating an estimated $5.6 billion (U.S.) annually (Dicks et al. 1996). It also exhibited considerable expansion throughout the

1980s and 1990s, more or less reflecting global trends in aquaculture growth. U.S. production increased from 219,619 tonnes in 1987 to 314,657 tonnes in 1996 (Table 1), while the farm-gate value has risen from $437.1 million (U.S.) to $885.6 million (U.S.) during the same period (USDC/NOAA/NMFS 1998). Most of the increase in production and value during this ten-year period is primarily due to one species, the channel catfish (*Ictalurus punctatus*), while the development of most other sectors of the U.S. aquaculture industry have lagged behind (USDC/NOAA/NMFS 1998).

Table 1. U.S. aquaculture production in tonnes (UDC/NOAA/NMFS 1998). Data for most groups of fish/shellfish are for those produced and sold for food.

Year	Catfish	Crawfish	Trout	Baitfish	Oysters	Salmon	Other Shellfish[1]	Misc.[2]	Total
1987	127,232	31,752	25,513	11,794	10,853	1,825	2,826	7,824	219,619
1988	133,861	29,868	25,416	11,975	11,067	3,074	2,446	9,201	226,908
1989	155,085	29,937	25,187	10,889	10,095	3,857	2,035	11,500	248,585
1990	163,492	32,205	25,772	9,802	10,066	4,114	2,844	11,403	259,698
1991	177,297	27,481	26,954	9,608	9,359	7,599	3,411	12,312	274,021
1992	207,460	28,591	25,521	9,352	10,880	10,858	4,070	16,786	313,518
1993	208,207	25,757	24,785	9,332	11,067	11,466	5,918	11,370	307,902
1994	199,251	22,263	23,621	9,847	12,708	11,210	4,402	18,628	301,930
1995	202,706	26,375	25,371	9,870	10,533	14,204	3,148	21,206	313,413
1996	214,154	21,130	24,322	9,457	8,412	13,906	3,486	19,790	314,657

[1] Other shellfish includes clams, mussels, and salt water shrimp

[2] Miscellaneous includes striped bass, tilapia, ornamental/tropical fish, alligators, algae, aquatic plants, eels, scallops, crabs, and others

Overview of Aquaculture in the U.S. Great Lakes States

Aquaculture production in the eight Great Lakes states is characterized by great diversity with numerous species of aquatic organisms being cultured by more than 1,000 producers. This includes production of food-fish, baitfish, fish for stocking recreational and ornamental water bodies including fee-fishing operations, as well as aquatic plants for food, wetland mitigation, and water gardening. These organisms are cultured under a variety of conditions, ranging

from extensive culture in natural ponds and lakes (e.g., walleye, *Stizostedion vitreum*, fingerling production and wild rice, *Zizania aquatica*) to highly intensive raceway culture and indoor recirculating systems. Other culture systems include constructed ponds, tanks, and cage culture (but only in inland waters).

Numerous aquatic organisms are being cultured in the eight Great Lakes states (Table 2). The more commonly cultured types include many of those same species permitted for culture in Ontario.

Table 2. Common species currently cultured in the U.S. Great Lakes states.

Common name	Scientific name
Atlantic salmon[a]	*Salmo salar*
Chinook salmon[b]	*Oncorhynchus tshawytscha*
Coho salmon[b]	*Oncorhynchus kisutch*
Brown trout[b]	*Salmo trutta*
Brook trout[c]	*Salvelinus fontinalis*
Rainbow trout[b]	*Oncorhynchus mykiss*
Northern Pike	*Esox lucius*
Common carp (koi)[b]	*Cyprinus carpio*
Triploid grass carp[b]	*Ctenopharyngodon idella*
Goldfish[b]	*Carassius auratus*
Channel catfish	*Ictalurus punctatus*
Blue Catfish[b]	*Ictalurus furcatus*
Hybrid Striped Bass[d]	*Morone* spp. crosses
Largemouth bass	*Micropterus salmoides*
Smallmouth bass	*Micropterus dolomieu*
Bluegill	*Lepomis macrochirus*
Bluegill hybrids	*Lepomis* spp. crosses
Redear[b]	*Lepomis microlophus*
Black crappie	*Pomoxis nigromaculatus*
Walleye	*Stizostedion vitreum*
Yellow perch	*Perca flavescens*
Tilapia of the genera[b]	*Oreochromis, Sarotheradon, and Tilapia spp.*
White sucker	*Catostomus commersoni*
Fathead minnow	*Pimephales promelas*
Golden shiner	*Notemigonus crysoleucas*
Emerald shiner	*Notropis atherinoides*
Crayfish	*Orconectes, Procambarus, and Cambarus spp.*
Wild rice	*Zizania aquatica*

[a] Native only to Lake Ontario; introduced into other Great Lakes

[b] Not native to any of the Great Lakes

[c] Native to all but Lake Erie where it was introduced

[d] White bass (*Morone chrysops*) native to all of the Great Lakes but striped bass (*Morone saxatalis*) native only to the St. Lawrence River

Unfortunately, most historical time-series data for both the quantity and economic value of private aquaculture in these states are generally lacking. There have been some trout data that dates back to the late 1980s collected by the U.S. Department of Agriculture's National Agricultural Statistics Service on four of the Great Lakes states: Wisconsin, Michigan, Pennsylvania, and New York. However, time-series data for other aquacultural species goes back only several years at best, and are available for only a few of the Great Lakes states. In our opinion, the data that does exist are minimal estimates of what is actually being produced and sold, and there are virtually no quantitative data for those non-food or non-sport aquatic organisms (e.g., ornamental fish, tropical aquaria organisms, and most aquatic plants) in the Great Lakes basin. It is believed that this sector of aquaculture is large and diffuse, and it is estimated that the value of this sector equals or exceeds the total combined value of all food and sport sectors of aquaculture.

In response to a growing interest to quantify the size of the private aquaculture industry, the National Agricultural Statistics Service is undertaking the first-ever comprehensive Census of Aquaculture for 1998. Survey forms were mailed out in December to the nation's aquaculture producers to collect data for the 1998 calendar year. The census will provide a benchmark of the industry's size and diversity. Results from this census will provide the only source of uniform, comprehensive data on production and sales of aquaculture products. The census will be conducted every five years or as the industry requires it. The 1998 Census of Aquaculture data will provide practical information to: (1) help producers understand their industry and decide which species to raise, (2) facilitate program planning by aquaculture organizations, Congress, and State governments that help aquaculture operators receive the most for their investments, (3) assist suppliers of materials and services to allocate and distribute their goods and make other management decisions, and (4) enable policymakers to evaluate programs affecting aquaculture production. Results from the 1998 Census of Aquaculture will be available beginning in the fall of 1999 for free on the Internet at http://www.usda.gov/nass/ and at selected universities, colleges, and public libraries.

Table 3 presents estimated values for the main types of cultured organisms in the Great Lakes states with most of the data being obtained through an informal survey of the industry. The total value for all cultured organisms for 1994 and/or 1995 is at least $54.4 million (U.S.).

Table 3. Aquaculture in the U.S. Great Lakes States.
Farm-gate values are estimates for 1994 and/or 1995.

State	1994 and/or1995 farm-gate value (U.S.)	Dominant type	Other
Minnesota	$12,750,000	wild rice	baitfish, salmon/trout, walleye
Wisconsin	$12,000,000	baitfish	trout, walleye, yellow perch
Illinois	$3,000,000	channel catfish	largemouth bass, sunfish
Indiana	$3,000,000	goldfish	triploid grass carp, channel catfish, largemouth bass, sunfish
Michigan	$4,000,000	trout	baitfish, yellow perch, sunfish
Ohio	$2,000,000	trout	triploid grass carp, bass, sunfish
Pennsylvania[a]	$13,795,000	trout	ornamental fish, baitfish, hybrid striped bass
New York[a]	$3,867,000	oysters	northern quahog, trout, baitfish, salmon smolt
TOTAL	$54,412,000		

[a]Data from Spatz et al. (1996)

Future Outlook for the U.S. Great Lakes States

What are outlooks for the future of private aquaculture in the Great Lakes states? The potential is great, but there is cautious optimism as to how the industry will grow and expand over the next five years and into the 21st century. There will be continued interest and support at the federal government level, but politics and the state of the economy will dictate the magnitude and intensity of support for industry growth. The U.S. Department of Agriculture Regional Aquaculture Center program will continue, probably at its current level of funding of about $4 million (U.S.) per year, which is equally divided amongst the five Centers. Hopefully a revised National Aquaculture Development Plan will be approved defining what the federal government can and should be doing to stimulate and support a competitive and sustainable U.S. aquaculture industry. It is also hoped that the growing interest on the part of the private sector and by many state agencies within the Great Lakes region will continue. Therefore, it is predicted that the industry should continue to grow, particularly for some of the emerging species such as yellow perch, walleye, hybrid striped bass, and tilapia. There appears to be good potential for growth in the recreational fishing sector. Production of bait for angling, ornamental fish and plants for water gardening, or stocking of public waters through privatizing the state and/or federal hatchery operations system, are all potential scenarios for restructuring of the region's aquaculture industry.

Organization of Regulatory Policies and Industry Associations

Although private aquaculture has been practiced in some fashion in most of the region for nearly a century, it is only in the last twenty or so years that there has been serious interest by regulators and industry groups in coordinating this activity. Currently, all U.S. Great Lakes states have private sector aquaculture associations and most have either interagency advisory committees or task forces dedicated to promoting, managing, or improving coordination of the numerous client groups which interact with this industry (Table 4). Five of the eight states have legally defined aquaculture as agriculture and in the other three states aquafarming is recognized as being an agricultural activity. Aquaculture plans have been developed for Wisconsin, Illinois, Indiana, and New York. In all states, there has been formal, enabling

Table 4. Status of the aquaculture industry and policy development for the Great Lakes states.

Stage of policy development	MN	WI	IL	IN	MI	OH	PA	NY
Aquaculture association	✓	✓	✓	✓	✓	✓	✓	✓
Advisory committee/task force	✓	✓	✓	✓	✓		✓	✓
Defined in statutes as agriculture	✓		✓	✓	✓	✓	?	
Aquaculture plan		✓	✓	✓				✓
Enabling legislation	✓	✓	✓	✓	✓	✓	✓	✓

Table 5. Current regulatory environment in the Great Lakes states.

Regulatory policies[a]	MN	WI	IL	IN	MI	OH	PA	NY
Permit required for private culture	✓	✓	✓	✓	✓	✓	✓	✓
Wholesale or transportation permit required	✓	✓	✓		✓	✓	✓	✓
List of allowable species	✓		✓	✓	✓	✓	✓	
Allowable species determined on a case-by-case basis		✓						✓
Permit required for importation	✓	✓	✓	✓	✓	✓	✓	✓
Import of certain species prohibited	✓	✓	✓	✓	✓	✓	✓	✓

[a] Where the regulation is enforced on a case-by-case basis, only for certain species, or can be modified, the state/province designation is underlined.

legislation passed pertaining specifically to aquaculture. Michigan has passed an Aquaculture Development Act in 1996 and a bipartisan bill was introduced to the Pennsylvania legislature in 1997 which defines aquaculture as agriculture and calls for the development of a state plan for the industry.

All states require a permit for the private culture of most aquatic animals and many aquatic plants (Table 5). These permits are either issued by a natural resource agency or a department of agriculture. All states usually require a permit for importation (although there are numerous exceptions to this general rule), and there are federal importation regulations for salmonids that are predicated on controlling the spread of pathogens which can impact either wild or farmed fish. All states prohibit the importation of certain species of aquatic organisms, but specific, prohibited species vary from state to state.

For the relatively small size of the aquaculture industry in the Great Lakes region, there is a disproportionately large infrastructure of federal and state agencies, in consultation with private sector groups, involved in the management of various pieces of legislation, regulations, and other policy matters affecting the industry. This owes to the seemingly complex nature of a business which spans a wide array of resource, food safety, animal health, and environmental issues to name but a few. In concert with the rapid expansion of production which has occurred over the last decade and the good potential for future growth, it is likely that regulatory constraints will become even more pervasive, rather than less, which may represent the singularly largest constraint to sustainable growth of aquaculture into the next decade. This fact underscores the need for government and industry to maintain open and collegial negotiations to resolve various issues as aquaculture in this region makes the transition from a small to a moderate-scale farming activity in the Great Lakes watershed.

Impediments to Future Growth of Aquaculture

There are many factors which may impede the growth and progress of this regional aquaculture industry as it moves towards the next millennium. International competition from Norway, Chile, the Indo-Pacific region, and other areas threatens the profitability for farming certain species such as salmon and tilapia. These countries developed aquaculture quickly to take advantage of the global "windows of opportunity" that existed during the late 1980s and early 1990s when the world economy was expanding and the wild fishery was being over-exploited.

Adequately tested production technologies and economic and marketing data are unavailable for most organisms that have traditionally been raised in the region. Diversification into non-traditional species requires a lengthy trial and error period of research and development, pilot testing, and market development (Garling 1992). Many years may be necessary to commercialize a "new" species, even when the technology is readily accessible. The lack of firm biological and financial data have made it difficult to secure significant capital for financing projects.

Many of the species that aquaculturists would like to raise in the Great Lakes region require warmer water temperatures to maximize growth and production. Recirculating aquaculture systems (RAS) have been suggested as a means to meet these requirements. RAS often results in higher unit production costs which can seriously constrain profitability of the operations. Unless innovative new technologies are developed to raise these fish more cost-effectively, the region will only produce fish which are adapted to the regional climate and water quality conditions.

For the small farmer, there is a paucity of high quality and reputable processing plants that are convenient to deal with, which may influence new farms in the future to be larger and more vertically integrated. In fact, the economies of scale are such that small farms usually can only be competitive by producing some form of value-added product, and by providing a high level of customer service within a niche market.

The aquaculture industry considers the regulatory environment overburdensome and that it poses a formidable constraint to the region's industry growing more quickly and sustainably. Over-regulated in some areas, and under-regulated in others, the private sector deals with a complex, rapidly changing, and conflicting legislative environment which defies forward business planning in some cases. Slow access to water resources, lack of readily available chemotherapeutic agents, and difficulty in dealing with environmental and resource lobby groups are either direct or indirect examples of regulatory burdens that the aquaculture industry faces. Continued lack of public awareness of aquaculture and its products, also means that few people are sympathetic to an industry that they know little about.

Finally, societal and consumer attitudes towards aquaculture will be based on the industry maintaining a relatively untarnished record of environmental stewardship and food safety. This will be especially true during the period when the industry is attempting to convince the buyer that fish is a healthful, reasonably-valued, food item that can compete with the conventional beef, pork, and poultry products that control the predominant share of the North American meat marketplace.

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APPENDIX 6

Expected Growth of Aquaculture: Ontario's Experience

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Introduction

In Ontario, fish culture has been practiced since the turn of the 20th century by the provincial government, mainly for lake and stream stocking. Fish culture remained exclusively a government endeavour until 1962 when changes to Ontario's Game and Fish Act allowed the private sector to raise and sell rainbow and brook trout for human consumption or for stocking purposes, and smallmouth and largemouth bass for stocking only. Since then, the commercial aquaculture industry has grown. In 1995, regulatory changes were made to make over 40 species eligible for aquaculture in Ontario. In 1997, 3,725 tonnes of trout were produced in approximately 200 facilities with a farm gate value of about $16 million (Cdn.)(Moccia and Bevan 1998).

Currently, rainbow trout accounts for over 95% of the production output from Ontario aquaculture. Other species such as tilapia, arctic char, baitfish, and bass are also produced commercially. Most aquaculture facilities are located in southern and central Ontario, though there has been expansion in northern Ontario, particularly in the waters of Georgian Bay.

The province has a number of competitive advantages to expand the industry in the near future. Whether or not this potential is achieved will depend on various factors, including government regulatory action, investments by the private sector, currency exchange rates and competition from other jurisdiction.

Growth Potential of Ontario's Aquaculture Industry

Factors supporting growth in Ontario's aquaculture industry include:

- **the industry is well-situated to serve the live fish or freshly-harvested fish markets in eastern Canada and the north-eastern and the mid-western United States;**
- **a stable consumer market exists for fish and fish products;**

- **Ontario has abundant water resources for both land-based and off-shore cage culture operations with potential for increased cage production on the Great Lakes;**
- **the Ontario aquaculture industry enjoys good access to equipment, services, and supplies, plus a high level of technical and scientific expertise within the university and industrial communities;**
- **there is government support for the industry through research, extension, and educational activities and by direct assistance through business management, leadership training and export marketing programs;**
- **some areas of the province and some First Nation groups view aquaculture as an opportunity for economic development and job creation; and**
- **health benefits occur from consuming high fat, cold-water fish (e.g., trout).**

Potential by Species

Many salmonid species have been cultured in Ontario over the past decade. Species such as Atlantic, Chinook, and Coho salmon have little production potential in Ontario because of the low cost of production from cage farms in the marine environment. Brook and brown trout will have a continuing demand for pond stocking and fishing clubs. The two species of salmonids with strong growth potential are rainbow trout and Arctic char.

Rainbow trout will continue to be the mainstay of Ontario's aquaculture production over the next decade. A large potential market for fresh Ontario rainbow trout boneless fillets exists within the north-eastern and north-central United States. Increases in Ontario's trout production will come from new cage culture sites and from pump-ashore systems. In the near future, the private sector will be cautious in developing new cage culture sites until the policy and regulatory environment becomes clearer.

Several groups are currently investigating large-scale, pump-ashore production systems. These land-based raceway or circular tank systems are located beside a large body of surface water and pump large volumes of water through the production systems. Opportunities also exist for production of rainbow trout in land-based production systems diverting water from streams dammed for power generation, generally located in northern Ontario. Under optimum conditions the rainbow trout industry in Ontario could double production within the next 5 years. This could result in the creation of 200 direct and indirect jobs.

Arctic char production in Ontario has gradually increased since culture of these species by the private sector was allowed in 1995. Arctic char is a relatively new species in the market place and because of the supply-limited situation, it commands a premium price, typically one and a half times the wholesale price of trout.

Two factors have limited the rapid growth of the Arctic char farming industry in Ontario. Reproductive efficiency has been lower than experienced for the domesticated trout species and the private sector has been unable to get licenses to culture char at new locations because of concerns over escapement. Nevertheless, the production of char was about 114 tonnes in 1998 with significant increases expected in 1999 due to two large Arctic char production facilities coming on-line in Northern Ontario.

The production of non-salmonid species for food was not allowed until regulatory changes to the Game and Fish Act in 1995. Changing demographics in the Greater Toronto Area over the past decade have provided a tremendous increase in the demand for live non-salmonid fish. Recent surveys of some of the fish importers has revealed that live fish imports from aquaculture producers in the United States exceeds 10,000 tonnes annually. There are significant opportunities for fish farmers in Ontario to displace some of the imports from the United States. Given the current Free Trade environment and the free movement of live non-salmonids across the border, the exchange rate will continue to have an influence on the cost competitiveness of imports and exports from and to the United States. Non-salmonid species that offer increased production potential in Ontario include: tilapia, striped bass, largemouth bass, yellow perch, walleye, and white sturgeon.

Summary

There are significant opportunities for Ontario's aquaculture industry in the next decade. Ontario has abundant supplies of high quality water, ready access to large domestic markets, and a well-developed industrial infrastructure. With the current favourable exchange rates for exports, Ontario is in the enviable position to take advantage of the large markets for boneless trout fillets in the north eastern and north central United States. Other species also show growth potential. Under optimal conditions, Ontario's total aquaculture production could reach 11,000 tonnes in five years.

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Appendix 7

Managing Effluents from an Intensive Fish Culture Facility: The Platte River State Fish Hatchery Case History

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Introduction

The Michigan Department of Natural Resources (Department) has operated a fish culture facility on the Platte River near Honor, Michigan since 1928. This facility has been involved in a long-term dispute concerning the effects of the hatchery on the Platte River watershed, in particular Big Platte Lake. There are many lessons to be learned from this experience concerning: the effects of fish culture operations on aquatic systems in the Great Lakes; the operation of a facility; and how to deal with effluent problems from intensive culture facilities. The objectives of this case history talk are: 1) to discuss the history of the Platte River State Fish Hatchery effluent problem; 2) to discuss the effects of effluents, both real and perceived, on natural systems; and 3) to discuss the measures taken and proposed to correct this problem.

Site Description

The Platte River State Fish Hatchery is located near Honor, Michigan in the northwest part of the Lower Peninsula. Deep glacial outwash deposits and extensive groundwater resources characterize this area. The hatchery is located at river kilometer 29.0 upstream from Lake Michigan and is upstream of a large inland lake, Big Platte Lake. The hatchery uses strictly surface water from the Platte River (46.6 million liters daily), Brundage Creek (26.5 million liters daily), and Brundage Spring (6.4 millions liters daily).

The facility was established as a trout rearing station in 1928 with an annual production of approximately 10,000 kg. During the period from 1966 to 1972, the facility was renovated to support the Department's Great Lakes salmon program and currently produces 62,000 kg annually using between 40,000 to 80,000 kg of food. The facility is currently the main coho

[1] The views represented in this extended abstract do not necessarily represent the official positions of the Michigan Department of Natural Resources.

salmon egg take location in the Great Lakes and produces most of the coho and chinook salmon needed by the Department's Great Lakes fishery management program. The current production targets for the facility are two million coho salmon at 36/kg and five million chinook salmon at 220/kg. Additionally, surplus salmon are harvested at a weir in the lower river just above Lake Michigan.

The hatchery discharges into the Platte River after passing through a large treatment pond, two hectares in size. The Platte River is a very stable river system because of the underlying glacial geology of the system with moderate natural productivity as measured by alkalinities between 100-200 mg/L. The river has a mean discharge of 3.8 m^3/sec, a 10% exceedence discharge of 4.4 m^3/sec and a 90% exceedence discharge of 3.2 m^3/sec. The river flows another 17.7 km to Big Platte Lake then on to Lake Michigan.

The waterbody that has been most effected by the operation of the Platte River State Fish Hatchery is Big Platte Lake, 16 km downstream of the hatchery. This lake is a 10.6 km^2 natural lake with a 502 km^2 watershed that is 93% undeveloped. It has a mean depth of 7.7 meters with a maximum depth of 29 meters. The lake is classified as oligo-mesotrophic with low nutrient concentrations, low algal productivity, and low dissolved oxygen in bottom waters during the summer. The water residence time has been calculated at 5.9 months.

Big Platte Lake Water Quality Problem

Currently, this lake has seasonal transparency problems because of calcium carbonate (calcite) formation. These "whiting" events occur most dramatically during periods of hot, calm weather in the late spring and result in high alkalinity concentrations that cause calcite formation, which drive down secchi disk readings to less than one meter. Local residents, as represented by the Platte Lake Improvement Association (PLIA), have in court depositions stated that these events did not occur prior to the reconstruction of the Platte River State Fish Hatchery and transparencies were usually greater than three meters. They have also stated that symptoms of eutrophication such as reductions in crayfish populations, disappearance of sensitive vegetation (bulrushes), reductions in mayfly hatches, the occurrence of dark polluted matter on docks and boats, and fishing becoming worse have occurred because of the effluents from the hatchery. Historic scientific data on these charges are lacking to support these statements and this case history really points to the need for more monitoring of surface waters near fish culture facilities.

Phosphorus has long been understood to be a limiting factor in plant growth in aquatic systems. It is also known that excessive algal blooms can produce major shifts in pH and can change the carbonate balance in lake systems. Thus, it is possible that effluents from the watershed could be related to the above noted problems in Big Platte Lake. Watershed loadings to this lake were as high as 3,260 kg annually in the late 1970s with the hatchery contributing 1,360 kg of this load and this loading is capable of causing water chemistry changes.

Overall, there are four potential sources in the watershed: nonpoint sources; hatchery effluents; salmon smolts stocked by the hatchery that die in the outmigration; and returning unrecovered adult salmon that die in the river system. Nonpoint watershed inputs of phosphorus have decreased from 4,100 kg annually in the 1970s to 2,000 kg in the late 1990s and all sides agree on this trend. Presently, the Department annually stocks an average of 787,000 coho salmon smolts that weigh 22,477 kg into the Platte River. Some of these smolts die on

their outmigration downstream or are eaten by predators. The loadings from this source are in dispute as PLIA estimates that the phosphorus contribution from this source to be 18.2 kg/year or greater and the Department estimates this source to be under 6.8 kg/year. There is also a sizable difference of opinion on the availability of this source to Big Platte Lake.

A number of adfluvial species return to the Platte River each year, but all of the attention has been focused on coho and chinook salmon. The total run of chinook salmon to the Platte River averaged 5,100 fish prior to 1988 and 3,500 since 1988. Only 450 of these fish are allowed to pass the lower weir facility annually with a total weight of 2,300 kg (10.3 kg of phosphorus). Annually, a total of 150 of these fish are harvested at the upper weir at the hatchery and angler harvest is estimated to be 70% of the unaccounted fish. The total run of coho salmon to the Platte River averaged 105,000 fish prior to 1988 and 47,000 since 1988. Only 20,174 of these fish are allowed to pass the lower weir facility annually with a total weight of 59,920 kg (236 kg of phosphorus). Annually, a total of 14,400 of these fish are harvested at the upper weir at the hatchery and angler harvest is estimated to be at least 80% of the unaccounted fish. PLIA claims that salmon carcasses are responsible for 100 kg of phosphorus annually to the Platte River system and the Department estimates 19.3 kg annually. There is also a sizable difference of opinion the availability of this source to Big Platte Lake.

Platte River State Fish Hatchery Court Case

By the 1980s, the local residents of Big Platte Lake came to the Department to express their concerns with the water quality of the lake. They pointed out that these problems did not occur prior to the reconstruction and expansion of the Platte River State Fish Hatchery. After meeting with the Department, the local residents did not see, nor were they made aware of, any major steps to improve the situation. Additionally, while this facility did have a National Pollutant Discharge Elimination System (NPDES) Permit issued by the Department, it did not control phosphorus discharges until the 1980 permit. It is the only controlled point source on the watershed. So there was a clear perception in the early 1980s that the Department ignored Big Platte Lake problems and did not adequately control effluents from the Platte River State Fish Hatchery.

Given the Department's lack of movement on the issue, the PLIA sued the Department under the Michigan Environmental Protection Act (MEPA). PLIA made the following points: the draft 1985 NPDES permit level of 636 kg phosphorus annually was not protective; not all sources of phosphorus were monitored or considered and that weirs, smolt stocking and hatchery discharge are all sources; and the Department was not actively taking steps to limit phosphorus inputs to the Platte River system. In 1988, the court agreed with the residents that the Department was polluting, impairing, and destroying Big Platte Lake and would continue to do so, and required significant changes in the operation of the facility.

In the 1988 court opinion, the Department was required to: reduce the 1988 loading of 420 kg annually with the intent of maintaining a Big Platte Lake phosphorus standard of 8 µg/L; feed fish low phosphorus food (<1.0% phosphorus); deepen the treatment ponds and improve the waste removal system; hire a court master to oversee the court order; and stop the migration of salmon at the lower weir. The migration part of the order was later modified to allow the Department to pass at the lower weir the first 20,000 fish, then 1,000 fish per week from August 15 to December 15. In response to the court order, the Department dredged the treatment pond in 1990; switched entirely to low phosphorus diets; installed a solids

collection system in the indoor rearing building; operated the lower weir as required; initiated a lower weir egg take facility feasibility study; funded a required experimental closed rearing system; and funded an intensive watershed monitoring system.

Results of Court Actions

Overall, watershed phosphorus loadings to Big Platte Lake have decreased since the 1970s highs of 4,100 kg to 2,000 kg annually in the 1990s. The direct percentage contribution of the hatchery has gone from 33% to fewer than 5% of the annual phosphorus loading to Big Platte Lake. This does not include the contribution of salmon smolt and adult mortality to phosphorus loadings, a point of contention between the parties. Transparency during the warm water period (May to September) has improved from an average of two meters in the 1970s to 3.5 meters in the 1990s. However, severe whiting events with transparencies less than a meter still occur although less frequently. Maximum transparencies have increased from an average of 3.5 meters in the 1970s to five meters and greater in the 1990s. It is important to note that significant changes in water quality came in stages with notable changes occurring after 1988.

Conclusions and Discussion

It is clear that effluents from intensive culture operations can have a measurable effect on receiving surface waters such as Big Platte Lake. The impact of the phosphorus loadings from Platte River State Fish Hatchery occurs in the spring when conditions are optimal for "whiting" events. Reductions in nutrients from Platte River State Fish Hatchery and the watershed have had a measurable effect on Big Platte Lake. There are significant correlations between lake phosphorus and transparency because of influence of phosphorus on algal production, which in turn influences pH and calcite formation. It is also clear that rehabilitation takes time as Big Platte Lake phosphorus values were only reduced 9% because of internal phosphorus cycling in spite of overall loading reductions of 24% in the 1990s. With the current phosphorus loadings of the hatchery (3-5% of the watershed total), it will become increasingly difficult to detect any additional changes from effluent management at this facility.

Many of the court ordered mitigative measures did work and major improvements in water quality in Big Platte Lake came about because of requirements to limit phosphorus in 1988, improvements to solids collection in 1990, and after the switch to low phosphorus foods in 1988. The measures that did have impacts included switching to low phosphorus diets; capturing solids as close to the source as possible without fragmenting particles; reducing hatchery production which directly reduces food use; and intensive monitoring of the watershed which allowed better understanding of the problem.

Some of the mitigative measures did not work and in fact increased phosphorus loading to the system. The Department dredged the treatment pond in 1990 to increase retention time and saw an immediate increase in phosphorus loadings to the Platte River as the littoral zone of the treatment pond was destroyed along with the plants that were tying up nutrients. This solution clearly overlooked the importance of the biological system in the pond and does lead one to actively manage the plant communities in these ponds to increase phosphorus uptake. Salmon migrations were stopped at the lower weir in 1992 and no changes in

watershed loadings of phosphorus were seen, thus this measure is not a clear solution to the problem. The court master concept did not work well because of a lack of clear direction and goals for the court master; a lack of knowledge about phosphorus cycling; and personality conflicts between the court master and the parties. Overall, the Department has spent over $2 million (U.S.) on the court case and the court master in the last ten years.

Current Status and the Future

Given the current improvements in Big Platte Lake, the Department applied for and received a new NPDES permit from the Department of Environmental Quality in 1998. The permit restricts the use of water to 166 million liters per day, the discharge of phosphorus to 200 kg per year with no more than 55 kg in any three months, and the discharge of total suspended solids to 1,000 kg daily (4-6 mg/L). We are also required to test for antibiotics in the effluents in response to concerns by local residents and the National Park Service. This permit is being contested by the local residents and is in administrative proceedings at this time.

Many things are still unresolved in this matter and the court case continues. Unresolved issues include: the effects of salmon smolt and adult carcasses on the phosphorus budget in this watershed which will impact the expenditure of $2 million (U.S.) on a lower weir egg take facility and how the Department will manage stockings on this system; the phosphorus loading target and how to measure it; the maximum water use; the redesign of the hatchery to reduce phosphorus loads even if the effect is not measurable; and whether the NPDES permit is valid given the ongoing court proceeding. If we can resolve the above issues, we can do more to reduce effluents from this facility as we have obtained $5 million (U.S.) in a capital outlay from the legislature to renovate the Platte River State Fish Hatchery. This commitment is contingent on bringing the court case to closure, as we must have certainty on what is required.

Finally, where do we go from here? First, we must bring the court case to closure to allow us to use the capital outlay funds to renovate the hatchery and to use these court related monies for other improvements. Second, we need to renovate Platte River State Fish Hatchery to further reduce effluents which will likely include partial reuse proposals to reduce effluent volumes, microscreening to reduce escapement of solids, and better vegetation management in the treatment pond using artificial wetlands and emergent plant processing to increase phosphorus capture. Third, we need to examine effluent treatment at all of our facilities to ensure that we do not impair the public trust resources we are charged to manage for the citizens of the State of Michigan.

APPENDIX 8

Aquaculture - Experiences and Lessons: Ontario Ministry of Natural Resources

by Alan Sippel and Mark Muschett

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In Ontario, fish culture has been practiced since the turn of the century by the provincial government, mainly for lake and stream stocking. Fish culture remained exclusively a government endeavor until 1962 when changes were made to Ontario's Game and Fish Act. This allowed the private sector to raise and sell rainbow and brook trout for human consumption or for stocking purposes, and smallmouth and largemouth bass for stocking only. In 1995, the regulations were changed to make over 40 species eligible for aquaculture.

Aquaculture or fish farming is a small but growing industry in Ontario. The province is well-suited for aquaculture because of its abundant high-quality water resources and its proximity to large markets in Canada and the United States. In 1997, some 4,250 tonnes of rainbow trout were produced in approximately 200 facilities with a farm gate value of about $23 million (Cdn.). This results in an estimated $65 million (Cdn.) contribution to the provincial economy and creates over 500 person-years of employment. Rainbow trout are the predominate species. Other species, including tilapia, arctic char, bass, and baitfish, are also produced commercially, but to a much lesser extent (total production value about $1 million (Cdn.)).

Most aquaculture facilities are located in southern and central Ontario, though there has been expansion in Northern Ontario, particularly in the waters of Georgian Bay and the North Channel of Lake Huron. The industry is comprised of numerous small-scale, essentially part-time operations, with fewer mid-sized and large-scale operations. Based on 1996 industry statistics, about 80% of the production total for the entire province came from only 8 large farms and 91% of production came from 20 farms. The best available estimates suggest that cage culture accounts for 70% of provincial production. Land-based ponds, circular tanks and raceways, as well as cages located in public waters, reflect the range of production technology used in aquaculture.

The Ontario Ministry of Natural Resources (OMNR) operates 10 provincial fish culture stations to culture fish for stocking. The stations are geographically distributed across the province. Lake trout, brook trout, and splake are the primary species but rainbow trout, brown trout, coho salmon, chinook salmon, Atlantic salmon, whitefish, and walleye are also produced. OMNR facilities produce between 8 and 10 million fish per year.

More than 12 federal and provincial agencies and 30 pieces of legislation potentially impact on the aquaculture industry. OMNR is the main licensing and permitting agency. OMNR issues the Aquaculture Licence which regulates where aquaculture can occur and which species can be cultured at any given location. Other licence conditions include a requirement to report specified disease agents, a requirement to maintain escape-prevention devices, and a requirement to report escapes above a specified number. For cage culture operations, there is also a licence condition to monitor and report on specified water quality parameters. Although there is a requirement to report the presence of specified disease agents, there is no requirement to monitor for those agents. The water quality monitoring and reporting requirements are being developed by the Ontario Ministry of the Environment (OMOE). OMNR also administers the Public Lands Act which governs the use of Crown or public lands in Ontario. A Land Use Permit is issued to provide a degree of tenure to cage culture operations on public waters.

Land-based fish culture operations that use more than 50,000 liters of water per day must obtain a Permit to Take Water from OMOE. OMOE is also responsible for issuing the Certificate of Approval to Discharge which regulates the quality of water being discharged from a culture facility. Neither the Permit to Take Water nor the Certificate of Approval to Discharge apply to cage culture operations.

Fisheries and Oceans Canada reviews proposals for cage culture operations to ensure that fisheries habitat concerns are protected. Canada Coast Guard must also review and approve cage culture operations from a navigation safety perspective.

Drug and chemical use at fish culture facilities is regulated by Agriculture and Agri-Food Canada through the Feeds Act and Pest Control Products Act and by Health Canada through the Food and Drug Act. A survey of commercial aquaculture operations suggests that very little drug and chemical use is occurring.

OMNR fish culture facilities approached the problem of improving effluent water quality by focusing on feed quality and diet design, as well as feeding practices. Substantial improvements in effluent water quality were achieved by reducing the phosphorus content, using highly digestible feedstuffs in the fish feed, and by reducing feed wastage. Also, OMNR has modeled fish growth, feed and oxygen requirements, and waste production for critical water quality parameters. A computer program, Fish-PrFEQ, is under development for use as a hatchery management tool, to assist with controlling waste outputs from fish hatchery operations. A test version of this model is available on the Internet at www.uoguelph.ca/fishnutrition/.

Furthermore, all OMNR fish hatcheries monitor effluent water quality. Most stations constructed or substantially modified since 1988 have had effluent treatment facilities installed and are required to report this information to the OMOE as a condition of their Certificates of Approval to Operate Sewage Treatment Works. All stations are expected to meet OMOE compliance limits for phosphorus and solids as the minimum standard of effluent water quality.

OMNR, in collaboration with the University of Guelph and cooperating institutions in other countries, has co-hosted a number of international symposia concerning the development of environmentally-responsible aquaculture. Industry approaches to mitigation are discussed elsewhere.

Suggestions for improving the ability to improve water quality protection include:

- **establishing more proactive legislation and policies;**
- **improving interagency cooperation;**
- **actively seeking industry input;**
- **defining science needs and finding ways to act on those needs;**
- **adopting an adaptive management approach in some situations;**
- **improving education, awareness and training; and**
- **recognizing that many issues will be site specific and that "broad brush" standards may not always apply.**

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APPENDIX 9

Water Quality Impacts from Aquaculture Cage Operations in the LaCloche/North Channel of Lake Huron

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Objective

The objective of this presentation is to share preliminary results of Ontario Ministry of Environment's (OMOE) water quality surveys around cage aquaculture operations in the North Channel, Lake Huron with participants of the Roundtable on Water Quality Impacts of Great Lakes Aquaculture. The presentation will include a brief history of OMOE's role and discuss some of the regulatory challenges in meeting OMOE's mandate to "protect water quality" and surface water goals to ensure that the surface waters of the Province are of a quality which is satisfactory for aquatic life and recreation (OMOE 1994).

Scope

Water quality data were collected from nine rainbow trout cage operations in Lake Huron; six from the North Channel, two from Manitoulin Island (Lake Wolsey and Robert's Bay) and one from Depot Harbour, Parry Sound, see Figures 1 and 2.

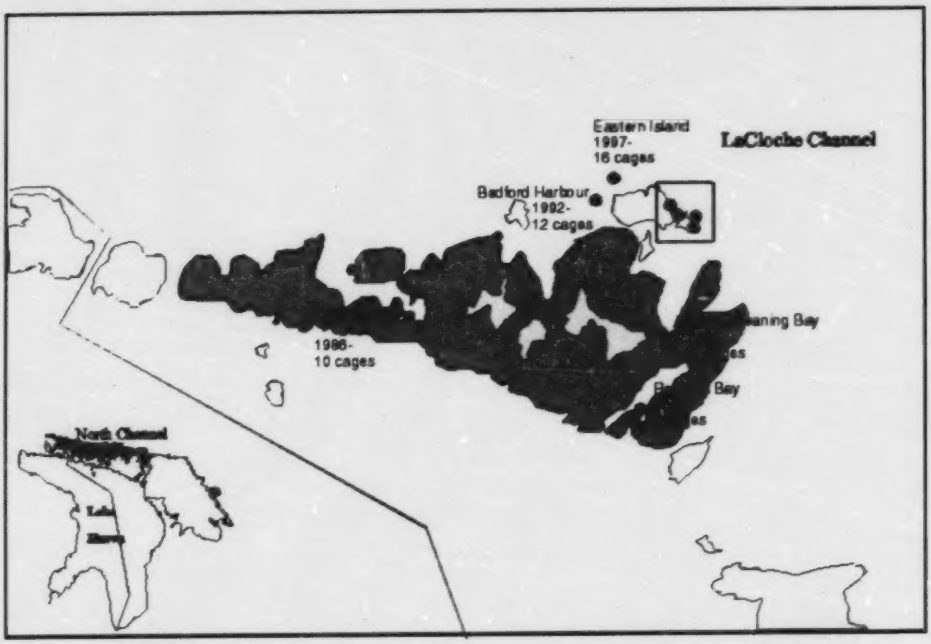
Lake Huron is a dilute, oligotrophic, low productivity lake which is sensitive to nutrient input. Historic Environment Canada water quality data indicate the North Channel averaged total phosphorus of <5µg/L, total Kjeldahl nitrogen 0.150 µg/L and dissolved oxygen levels >5mg/L, one meter above bottom (Stevens et al. 1985).

Background

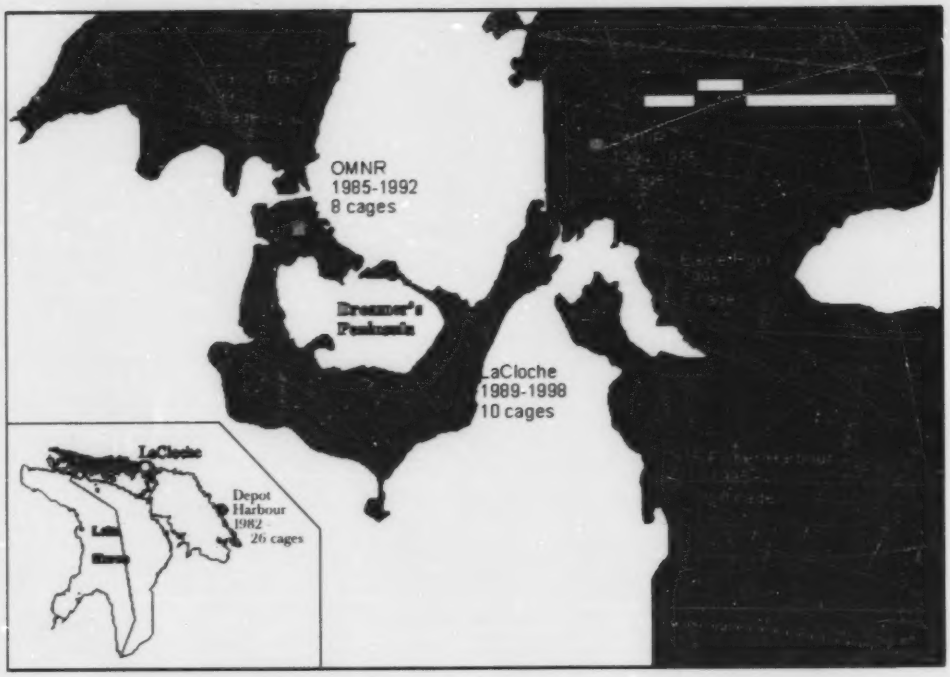
Aquaculture cage activities began in Northern Ontario in the early 1980s. At this time, sites required a Certificate of Approval for sewage works, under Section 53(1), *Ontario Water Resources Act.*

In the mid 1980s, OMOE did water quality impact assessments around three operations. At that time it was found that there was minimal impact around the cages, that surface water met Provincial Water Quality Objectives (PWQO) and that there was localized sediment

Figure 1. Cage locations around Manitoulin Island, Ontario.



Note: Manitouwaning Bay site was not sampled by OMOE in 1998, location is provided for information only.



Note: OMNR 1984-1985 site was not sampled by OMOE in 1998, location is provided for information only. OMNR 1985-1992 site is referred to as the forebay of the LaCloche site.

impairment immediately beneath the cages (Bowman 1984; Carbone 1985; Linquist 1986). Cautions were expressed at the time that these studies were conducted under low productivity levels (1-50 tonne fish) and that if production levels increased, impacts would be greater. There was a need for consistency in regulating this industry and a need to develop an appropriate method to determine the waste effluent quality and assess assimilative capacity of receiving waters (Conroy 1983).

Early water quality monitoring conditions required the industry to collect monthly composite samples upcurrent and downcurrent from the cages and analyze for total phosphorus and total suspended solids (TSS). The downcurrent total phosphorus was not to exceed background (upcurrent) by 50% and TSS was not to exceed background (upcurrent) by 100%. There were no requirements for dissolved oxygen profiles nor secchi disc readings at that time.

In 1994, OMOE's legal branch advised Regional staff that a Certificate of Approval did not apply because there were no sewage "works", wastes were neither collected nor treated. Ontario Ministry of Natural Resources (OMNR) then became the lead permitting and licencing agency of the Provincial government. The industry continued to grow in number of sites and expansions at existing sites. OMOE worked with OMNR to get water quality monitoring requirements on the Land Use Permit, offering the industry a "one-window" approach to Provincial requirements.

Current

In the mid-1990s, the public expressed concern regarding the expanding cage aquaculture industry in the North Channel. Public complaints were being received regarding algal growth in the LaCloche Channel. In September 1997, OMOE conducted an inspection of two aquaculture operations in the LaCloche Channel, referred to as Grassy Bay and the LaCloche site.

Grassy Bay exhibited good dissolved oxygen levels in the stratified deeper waters (5.2 mg/L dissolved oxygen and water temperature 7°C). Some dissolved oxygen depletion occurred directly beneath the cages in the bottom 2 meters (1.6-2.8 mg/L dissolved oxygen), but the system was still aerobic. Total phosphorus levels ranged 6-10 µg/L (PWQO, 10 µg/L).

LaCloche site had similar water temperatures 20°C surface to 7°C bottom and the basin was stratified. Dissolved oxygen levels were poor: surface to 12 meters depth were 5-9 mg/L dissolved oxygen, depths greater than 13 meters had 0 mg/L dissolved oxygen (maximum depth 41 meters). The anoxic conditions encompassed the entire hypolimnetic volume over a 250 ha area. Total phosphorus levels ranged from 16-26 µg/L in September and averaged 40 µg/L in October 1997. Secchi disc readings were reduced and an algae bloom was visible.

An August 1985 OMOE survey of the forebay of this area, found hypolimnetic dissolved oxygen levels of >5 mg/L near bottom and total phosphorus levels of <5 µg/L. PWQO for total phosphorus are 10 µg/L (for a high level of protection in waters typically below this level). OMNR manages this area as a cold water fishery and the PWQO for protection of cold water fishery is 6 mg/L dissolved oxygen at 10°C or 54% saturation. The combination of anoxic conditions and high phosphorus loadings resulted in additional phosphorus release from the sediments.

Morphometry of the site indicated that hypolimnetic waters would not readily mix with surface waters (fall turnover was not complete until early November). Depth contours of the area show several distinct deep holes in the basin with steep drop offs (see Figure 3). The bay is restricted in flow both at the inlet (culvert) and the outlet (flowing into McGregor Bay), flushing rate would be low.

The water quality impacts at this location were significant. Estimated 1997 loadings from the cage operation were 1.2 tonnes phosphorus, 7 tonnes nitrogen, and 38 tonnes solid waste. Immediate action was warranted and OMOE recommended that nutrient loadings be reduced immediately and that input of oxygen demanding solids (fish food and waste) be ceased.

An abatement process began in which OMNR and OMOE negotiated with the company and requested proposals to reduce loadings. The company indicated that alternative technologies (i.e., bags) were not economically feasible and the company could not present other proposals to reduce loadings. The parties agreed to a six month phase out of the operation over the winter, so the company could meet market demands. All fish were removed from the site by May 1, 1998 and the Land Use Permit was not reissued.

OMOE conducted an extensive monitoring program of eight other cage operations (plus LaCloche) in 1998 to assess water quality. Sites were sampled during spring turnover, peak stratification (summer) and fall turnover. During spring turnover, all sites had oxygen levels (>6 mg/L) at the bottom and most sites had <10 µg/L total phosphorus (exceptions: LaCloche 20 µg/L and Lake Wolsey 11 µg/L phosphorus[1]).

During summer and fall samplings, impacts varied on a site specific basis, with morphometry and flushing rate being the determinate factors. In some cases, in shallower water (<20 meters), a thermocline would form but surface mixing was sufficient to prevent a hypolimnion from forming. Other sites with deeper (>20 meters) isolated sub-basins, stratified forming a hypolimnion. Other sites were well flushed and their bottom waters mixed well with the main channel.

Cages which were in generally 16 meters water depth were surface mixed, which supplied a continuous oxygen supply to surface waters. Oxygen depletion was evident two meters above bottom at these sites (dissolved oxygen <1 mg/L). Dissolved oxygen levels of <1 mg/L were also found in the hypolimnion of isolated sub-basins (except Lake Wolsey, >1.6 mg/L dissolved oxygen). Sites which were not stratified, formed a thermocline and were well mixed with the main channel, dissolved oxygen levels were maintained >6 mg/L.

Individual total phosphorus readings from the perimeter of the cages ranged from 2-36 µg/L, ice-free averages ranged from 7-17 µg/L. Most sites bordered on the PWQO of 10 µg/L.

Overall, sites which were sheltered and had low flushing rates experienced oxygen depletion in the bottom 1-2 meters and some oxygen depletion in hypolimnetic waters of isolated sub-basins. None were as dramatic or significant as the LaCloche site. However, the combination of elevated total phosphorus (above historic 5 µg/L phosphorus) and oxygen depletion at some sites will necessitate abatement and management programs.

Establishing "control" locations proved to be difficult. Lakes or "lake-like" restricted basins would be well mixed during spring and fall turnover and, over the long term, effects from the cage operation would be distributed throughout the lake. In sites which were well flushed,

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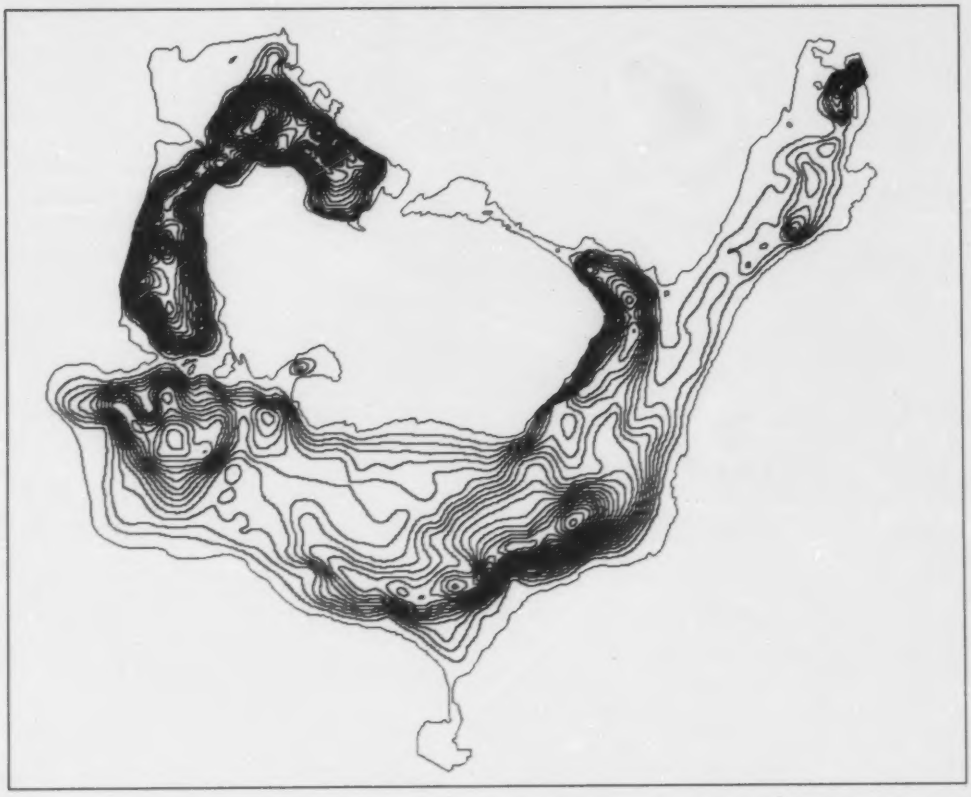
[1] Lake Wolsey in May 1986 (prior to cage operations) was 11 µg/L phosphorous, indicating that Lake Wolsey may not be typically below 10 µg/L phosphorous; therefore, a PWQO of total phosphorus of 20 µg/L would apply for this site.

Figure 3. LaCloche two meter site contours, maximum depth 41 meters (135 feet).



effluent would be diluted quickly, but may have been washed further afield. "Control" locations could be compromised. This emphasized the need for accurate background pre-operational data, including dissolved oxygen profiles from surface to bottom during stratification.

Environment Canada's Lake Huron 1980 cruise data provided historical data for comparison. Zone 1 (Grassy Bay) and Zone 19 (Frazer Bay) covered most of the cage locations with background total phosphorus levels of 4 and 4.8 µg/L and total Kjeldahl (TKN) levels 0.2 and 0.4 µg/L, respectively. 1998 sampling by OMOE showed an increase in total phosphorus and TKN levels around the perimeter of the cages when compared to historic 1980 Environment Canada data.

Current action is focusing on individual site specific effects. Consideration must also be given to the cumulative effects of these operations. Cho (1998) estimates waste output and effluent quality from rainbow trout operations to be: total phosphorus 5.11 kg, nitrogen 30.64 kg, and solid waste 164.3 kg per tonne of fish produced (this is based on low phosphorus feed and best management practices). Estimated yield from eight sites in North Channel and one site in Depot Harbour is 3,000 tonnes of rainbow trout. Based on Cho (1998), this would yield an approximate loading of 15 tonnes total phosphorus, 90 tonnes nitrogen, and 500 tonnes solid waste per year. The industry predicts the production level will double in the next decade (possible 30 tonnes phosphorus loading).

The 1978 Great Lakes Water Quality Agreement states that objectives for Lake Huron are to maintain oligotrophic state and relative algal biomass with a lake-wide target load for total phosphorus of 4,360 tonnes. In 1980, total estimated phosphorus load to Lake Huron was

4,799 tonne (industrial portion was three tonnes and municipal load 121 tonnes)(Dolan et al. 1986). The growing aquaculture industry will be a significant direct phosphorus contributor to Lake Huron and should be included in future Lake Huron phosphorus loading calculations.

Repeats of Environment Canada's ambient water monitoring cruises will help to assess cumulative changes over the years.

Conclusions

Aquaculture cage operations can cause eutrophication, phosphorus increase, algae blooms, oxygen depletion, and localized sediment impairment. Significance of the impact varied from minor to adverse, principally dependant on loadings, morphometry, and flushing rate.

Proper siting of cage operations is critical. This requires pre-operational water quality monitoring, particularly in spring and late summer. It also requires knowledge of site morphometry and an ability to assess the assimilative capacity of the site.

A complete, cost effective, operational water quality monitoring program is essential to ensure continued protection of the environment. Targets should be set to trigger abatement action and prevent adverse effects from occurring. The onus would be on the industry to collect these data and evaluate site suitability.

Inspection and audit roles of Provincial agencies sometimes require that surface water management decisions be made on a limited amount of data. It is critical that operators be required to conduct a water quality monitoring program which will adequately describe the fate of the effluent which they discharge to the environment and its effects on the receiving water. Developing appropriate siting criteria and implementation of an operational monitoring program would be a benefit to both the operator and the environment.

Recommendations

1. **A complete, cost effective water quality management program should be developed with the industry. Operators are responsible for the collection and reporting of data.**
2. **Trigger limits should be set on a site specific basis, which would initiate abatement action.**
3. **Operators should collect water quality data from potential sites and do a site assimilative capacity study prior to submitting an application for a new site.**
4. **An assessment of existing aquaculture effluent and modeling science should be completed and adapted for the Great Lakes freshwater environment.**
5. **Environment Canada should continue its ambient water monitoring of stations in the North Channel and Frazer Bay areas.**
6. **Cumulative effects and total phosphorus loadings to Lake Huron from the aquaculture industry should be evaluated.**
7. **Technologies to reduce waste effluent loadings should be explored.**

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Appendix 10

Minnesota's Experience with Net Pen Aquaculture in Mine Pit Lakes

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Introduction

Minnesota Aquafarms, Inc. established a large-scale net pen salmon and trout culture facility near Chisholm, Minnesota in 1988. The aquaculture facility was located in an area which previously had been extensively mined for iron ore. The strip mining activities resulted in the development of several large, deep pits. The pits had to be continuously dewatered during mining operations to prevent the inflow of groundwater from interfering with mining activities. In some respects these large pits could be viewed as very large open wells. The mine pit lakes are very different than natural lakes for many reasons. Mine pit lakes in the project area range from 30-120 meters in depth, have very small watersheds, have very small surface areas, have very short fetches, and are filling up with groundwater in some cases at rates of several meters per year. Typically these lakes have very low nutrient concentrations, have very deep water clarity, and are meromictic. Shorelines and lake slopes are very steep, lack vegetation, and are highly erodible. Since a number of the mine pits were very close together, in many cases the pits were linked by mine shafts or tunnels. Sometimes the tunnels or shafts were collapsed upon closure of the mine, but even so, the fractured nature of the rock allowed for interchange of water between pits. Some of the mine pit lakes provide the drinking water supply to neighboring communities.

Aquaculture Operations

Chinook salmon and rainbow trout were the two principal species raised at the Chisholm facility. The facility received a National Pollutant Discharge Elimination System (NPDES) permit which authorized the production of 1.9 million kg per year of fish with the corresponding level of manure waste generated. Although the number remains proprietary, it is estimated that from 1988 to 1994 a little over 1.4 million kg of fish were produced. At the end of the production facility's existence there were 750,000 fish (173,000 kg) being held in 22 net pens in the Sherman pit.

The fish reared in the Chisholm mine pit lakes were held in several large net pens. The design of net pen fish rearing facilities is quite different than conventional or traditional on-

land systems. At a net pen facility, floating cages are used to contain the fish. At the height of production, fish were held in sixty 15 meters deep nets. The salmon and trout within the net pens were fed a dry fish food which was hand thrown or mechanically blown into the nets. The fish food would sink toward the bottom of the net, and the fish would consume it on the way down. Several thousand kilograms of fish food per day were fed to the fish when the facility was operating under a normal mode. The food which was not consumed was lost through the bottom of the net and continued down to the bottom of the mine pit lake. The company experimented with utilizing a floating fish food, but rejected it due to increased cost and poor conversion rates.

The consequences of feeding several million fish held captive in the nets caused a concurrent problem of waste (manure) production. Fish excreted both soluble and insoluble waste into the net pens. The insoluble fish waste acted the same as the waste food in that it sank and passed through the net bottom and ultimately ended up on the mine pit floor. The soluble portion excreted in the net was lost to the surrounding water body. Violations of the company's NPDES permit phosphorus limit (33 µg/L) resulted in the Minnesota Pollution Control Agency (MPCA) requiring Minnesota Aquafarms to utilize a waste collection system for the facility.

The system consisted of a large funnel net below four net pens. The funnel net collected the insoluble waste that fell through the nets and concentrated the waste in the collector cone. Waste in the collector cone was then pumped out to a holding pond prior to land application. A pilot test of the system showed the efficiency of removal at 31% for solids, 39% for phosphorus and 10% for oxygen demand. Although the pilot showed these efficiencies, once in operation many problems occurred which we believed lowered the efficiencies and made operation of the system extremely problematic. Mechanical problems with the pumps and clogging of the net panels with waste and attached algal growth, which required the net to be hauled up and cleaned regularly, were two of the main issues. Ferric chloride was added to the net pens to enhance precipitation of phosphorus and collection effectiveness.

Environmental Concerns

Nutrients

The mine pit lakes are oligotrophic, having phosphorus levels less than 10 µg/L, less than 3 µg/L of chlorophyll *a*, and a secchi disc reading greater than three meters. The first pit lake to experience net pen activities was Twin City-South. This is a 28.3 hectare lake with a maximum depth of 69 m. During most of this time the lake was artificially mixed and aerated. The lake continued to be mixed after aquaculture activities ceased in July of 1993. Total phosphorus values began at 10 µg/L in 1988, rose to a high of 94 µg/L in 1992 and returned to near 10 µg/L in 1994 (Table 1). Dissolved inorganic nitrogen rose from 363 µg/L in 1988 to a high of 2,043 in 1993 before dropping to 1,228 µg/L in 1994. Chlorophyll *a* rose from 2.9 µg/L in 1988 to a high of 22.5 µg/L in 1991 before dropping to 1.5 µg/L in 1994.

The second pit to experience net pen aquaculture was Sherman Lake. This lake has not undergone the scrutiny that the Twin City-South Mine has undergone. The one key parameter measured in the Sherman pit until the operation ceased in 1995 was phosphorus. The phosphorus concentration rose from below 10 µg/L before aquaculture began to levels above 250 µg/L towards the end of the operation.

Table 1. Twin City-south Pit Lake surface summer (May-Sept.) values (Axler et al. 1995)

	Total Phosphorus (µg/L)	Dissolved Inorganic Nitrogen (µg/L)	Chlorophyll *a* (µg/L)
1988	10.2 ± 7.8 (3)	363 ± 105 (3)	2.9 ± 3.6 (3)
1989	34.0 ± 7.0 (22)	420 ± 108 (8)	11.4 ± 5.5 (21)
1990	65.5 ± 16.4 (28)	881 ± 58 (12)	8.9 ± 3.3 (27)
1991	77.5 ± 6.2 (26)	1,249 ± 146 (11)	22.5 ± 9.4 (23)
1992	94.6 ± 7.5 (24)	1,969 ± 146 (10)	4.0 ± 2.0 (24)
1993	51.6 ± 13.4 (28)	2,043 ± 233 (11)	5.5 ± 2.3 (28)
1994	14.6 ± 3.4 (22)	1,228 ± 180 (11)	1.5 ± 0.4 (22)

Therapeutics

The aquaculture company assured the MPCA at the beginning of the operation that no therapeutics would be necessary to treat the fish for diseases. This was soon proved to be untrue. Within a short time period, the company submitted a request for the use of therapeutics to control fish diseases. The use of therapeutics in the mine pits which were connected to other mine pits and ground water used for human drinking water became a volatile emotional issue with the people who used the drinking water. Eventually the company was given approval to use Terramycin antibiotic for disease control at levels that were not hazardous to the drinking water supply. A concern raised by the Minnesota Department of Natural Resources was that the widespread use of therapeutics would potentially select out disease organisms resistant to the antibiotic and that these antibiotic-resistant organisms could infect natural populations.

Persistent toxics

The presence of low levels of persistent bioaccumulative chemicals such as PCBs in the food fed to the fish was identified as a concern. The chemicals were present in the food due to the use of fish oils and other parts in making the food. No problems were found in the fish flesh offered for sale.

Political Concerns

The political ramifications of this aquaculture issue were very strong. The loss of the mining industry in this area reduced the jobs available to local citizens and was devastating to the local economy. The aquaculture venture promised a new industry and jobs. The mine pits were viewed as sterile bodies of water with little or no use by many. Those who took their drinking water from the pits felt otherwise, so a natural confrontation arose. The threat to drinking water and the pollution of the mine pits versus jobs for the local economy split the local community and the state legislature. The MPCA found itself in a common position of being in the middle and being attacked by both sides.

Lessons Learned

Restoration efforts

The restoration effort of the mine pit lake, Twin City-South, which included intensive aeration, alum addition, and fallowing, has led to a rapid return to near baseline conditions, which is oligo-mesotrophic status. This restoration was facilitated greatly by the fact that the steep shoreline conditions caused high ambient erosion which buried the nutrient-rich sediments below a layer of inorganic sediment. This isolated the nutrient-rich sediments from the overlying water column. Also, continual inflow of nutrient-poor groundwater diluted the nutrients.

Closure efforts

Minnesota Aquafarms filed for bankruptcy in February 1995 and the operation was taken over by Inter-Tribal Business Network. This appeared at a critical juncture due to problems which were being experienced by Minnesota Aquafarms. Minnesota Aquafarms had no resources with which to continue paying staff, paying for power for lake circulation, or maintaining the net cleaning activities. The net pens had to be regularly cleaned or else waste and algae would clog the nets, reducing the amount of water flow-through and oxygen available to the fish. The fish in the net pens were in danger of dying and the state was set to declare an emergency. No one wanted 750,000 fish to die needlessly in the nets, but the basis for the state to declare a health emergency, which is required by state law for the MPCA to act, was difficult to determine. Two solutions were available: (1) let the fish go, or (2) provide the resources to clean the nets. The state did not own the fish, so they couldn't just be released because recapture would have been extremely difficult and providing state resources to a private entity was not viewed with favor. No decision was required on the state's part since Inter-Tribal took over the entire operation. They maintained the nets, sold the fish that were at the appropriate size, and eventually released the rest of the fish to the lake.

Over the years of net pen aquaculture, several hundred thousand fish had escaped the net and had formed a free-roaming population which fed beneath the operating nets. All natural food had been consumed. When feeding stopped and the smaller fish were released, they became food for the larger fish. The released fish and the free-roaming fish were utilized as a sport fishing operation for approximately two years after the aquaculture operation ceased. Inter-Tribal would rent boats and charge a fee for fishing in the mine pit lake.

Summary

Minnesota's experience with net pen aquaculture was a long and tortuous affair. Environmental and political issues caused a great deal of controversy for the local community, Minnesota state government, the state Legislature and the project owners. At the completion of the effort an estimate of over 20,000 MPCA staff hours went into managing and dealing with this one facility.

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Appendix 11

British Columbia Experiences

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Introduction

In 1997, salmon farming production in British Columbia reached approximately 35,000 tonnes valued at about $225 million (Cdn.). Farmed salmon is B.C.'s largest agricultural export. The salmon farming industry has 100 marine sites and 19 freshwater sites – 17 hatcheries and 2 lake net pen sites – for production of 12-14 million smolts. Atlantic, chinook and coho salmon are produced. Some individual farms are licenced to produce in excess of 1,000 tonnes on an annual basis. Freshwater production of trout and charr for the table market is less than 250 tonnes annually. Experimental work on halibut and blackcod is in progress. Direct and indirect employment attributed to the industry exceeds 2,500 full time positions.

Marine feed conversion maximum is 1.5:1 so total feed utilized is about 60,000 tonnes. Feeds are nutrient dense. Delivery systems vary and are designed to optimize uptake. On a mass balance basis, input of nitrogen to coastal waters is a small fraction of inputs from sources such as the Fraser River.

In 1986, farm siting criteria included: avoidance of areas of "significant" fish habitat; distribution of farms to be a minimum of 3 km apart; a minimum of 3 cm/sec average flow; consideration of depth, current velocities, and farm orientation; use of a rudimentary model to predict when assimilative capacity would be exceeded; and low farm production level – circa 200 tonnes.

Farms were located for economic reasons – distance to market, supplies, etc. – as much as for biophysical reasons. There was a lot of feeding the water and not the fish-feed conversions of 6:1 were not unheard of. Accumulation of sediments occurred to the detriment of the farm itself in a few cases. There was no indication that dissolved nutrients were affecting algal production, especially toxic algal blooms. Several studies have shown that the areas impacted by sediments are remediated by natural processes over a period of months to years. Industry moved to cooler northern waters, cage design and anchor systems improved thus allowing use of more active sites.

In the mid 1990s, improvements in feeds and feeding practices – feedback and video monitoring systems – have reduced levels of impact. Fallowing is used when possible as are single year-class sites. Cross (1996) summarized observations from a series of investigations on

sedimentation under farms and determined that production has increased several fold on individual farms while sediment accumulation has decreased. These changes are attributed to improvements in feeds and feeding practices as well as better site selection. There is a move to the use of performance-based standards to determine level of production, rather than reliance on regulated production levels.

The ability to determine optimum sites has improved. Circulation dynamics (evaluating backeddy potential and mass transport potential for the site), measuring water column current velocities to ensure optimum dispersion of waste materials and sufficient movement at the sediment-water interface, assessing bottom substrate to determine whether it is depositional or non-depositional, choosing adequate depth to make optimum use of tides and currents, and matching farm size and waste material loadings are all important considerations.

Additionally, currents should not be predominantly onshore; recommended surface currents should be >10 cm/sec, currents at 15 meters should be >5 cm/sec and be >3 cm/sec one meter above the bottom. Water depth should be >30 meters with bottom sloping offshore, biotically sensitive resources (e.g., eel grass, kelp etc.) should be avoided, and sites should not be placed in bays.

A number of models have been created to attempt to predict release of solid and dissolved outputs of farm operations and their effects. In British Columbia, a Modular Aquaculture Modelling System (MAMS)(Chandler and Carswell 1995) was designed to try to integrate and predict the effects of multiple sites to determine whether there is possible interaction between sites from dispersion of metabolic waste products, utilization of oxygen, etc. Further development of the model has been put on hold pending response to the recommendations of the provincial Salmon Aquaculture Review.

The coastal lakes of British Columbia are among the most nutrient poor and unproductive freshwaters in the world (MacIsaac and Stockner 1995). Waters are soft, neutral to slightly acidic with low phytoplankton productivity with phosphorus levels ranging from 3-6 µg/L. Lake and river fertilization is used to increase production of wild fish (e.g., the Department of Fisheries and Oceans may fertilize sockeye lakes with 40-150 mg phosphorus/meter^2/year). Lake net pens are used for enhancement of wild salmon and trout. These have low densities and relatively low biomass. Two lakes are used for commercial smolt production, Georgie Lake on Vancouver Island and Lois Lake on the mainland. There is currently a moratorium on the use of additional lakes for smolt production until a response to the Environmental Assessment Review and acceptance of guidelines.

Georgie Lake was intensively studied in 1992 and 1993. Georgie Lake is 8.5 km long with a mean depth of 16.3 meters (maximum 42 m) with a surface area of 4.7 km. Sediments are naturally high in organic matter. Georgie Lake supported production of 8-14 tonnes of Atlantic salmon smolts annually between 1989 and 1994. Maximum feed utilized in this period was 21 tonnes in 1989. This study concluded that synoptic water quality studies are of limited value as effects are ephemeral and easily masked by water flow. Periphyton did accrue on sampling plates at a station as far as 200 meters away from the net pens. Periphyton samplers are a useful integrator of the effects of nutrient addition. Microbial foodwebs were enhanced as were phytoplankton and zooplankton. Nutrient loadings from the net pen operation were at the low end of areal loadings used by Department of Fisheries and Oceans to fertilize coastal sockeye lakes. Development of loading criteria for locating additional net pen sites will require the use of lake specific information.

Current lake net pen guidelines (DRAFT) include: lakes should be larger than 160 ha and preferably be landlocked; be oligotrophic with total phosphorus less than 10 µg/L at spring turnover; fish production should not lead to phosphorus concentrations above 15 µg/L; minimum depth under net pens should be 10 meters; a waste management permit may be required; there will be annual relocation of net pens to decrease sediment buildup; operational environmental monitoring will be instituted; other social and biological criteria will apply (e.g., presence of rare or endangered fish); angler effort; whether the water supply is used for domestic consumption; and absence of sockeye or kokanee salmon.

Summary

Improved husbandry and feeding practices in combination with improved siting has reduced the degree of sedimentation. In marine waters, dissolved nutrients do not appear to influence productivity to any significant extent – there is no documentation that salmon farming influences the development or severity of algal blooms. At current levels of production, net pen operations are not evidently shifting productivity in coastal lakes. The Environmental Assessment Review recommended a move to performance-based standards, rather than a regulated production limit based on biomass modeling to control sedimentation at farm sites.

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Appendix 12

A Farmer's Perspective

by Gord Cole

Aqua-Cage Fisheries

Comments on Regulations and a Case Study of an Environmentally Friendly Farm

Introduction

Aqua-Cage Fisheries

Aqua-Cage Fisheries Ltd. has been operating a cage culture fish farm in Georgian Bay since 1982. This was probably the first use of Norwegian-Style cage culture in freshwater anywhere in the world. It is possibly the oldest continuously operated cage farm anywhere in North America. This farm demonstrates the sustainability and minimal environmental impact of a typical fish farm. Aqua-Cage is an environmentally pro-active company, as are most Great Lakes cage farmers. Large amounts of scarce time and money are spent on pro-active environmental projects. The few exceptions, farmers who are not responsible, are why government regulations are required. Appropriate regulations are those which effectively prevent undesirable impacts, no more and no less.

Aqua-Cage has been operating in the same location since 1983 (a different location was used in 1982). There have been no public complaints. The farm consists of 26 cages each of which is 280 m^2 or 370 m^2. Five or six cages hold young fish and the rest have fish which will be sold that year. Fingerlings are purchased from a commercial hatchery and grown for 14-15 months. Market size is 1 kg plus. The grow-out period includes low growth in November and almost no growth December through April. Biomass peaks in the fall and declines about 80% over winter as fish are sold. Other cage sites in Georgian Bay have similar production cycles.

Aqua-Cage actively works to minimize environmental impacts. The two major components of the environmental program are fallowing and low pollution feed.

Fallowing

Aqua-Cage moves their cages seasonally. The fish are kept in the harbour from mid fall until late spring. The harbour is 9-10 meters deep with a good current. The cages in the harbour are protected from ice damage and remain easily accessible during the winter harvest. Fish

and cages are moved into a more open location during the summer. This basin is over 3 km^3 in volume and the water is estimated to exchange several times a year. The basin has a maximum depth of about 160 meters, with about 60 meters of water where the nets are moored in the summer.

Each location fallows for part of the year. Sediments that accumulate under the cages during the feeding period, dissipate during the fallowing period, preventing year to year accumulation. Moving the cages twice a year is time consuming and expensive. It is worthwhile for Aqua-Cage because it allows much greater fish production with very low environmental impacts. Seasonal fallowing is not appropriate for most farms, but other fallowing strategies may be used. It should be noted that farms require two or more sites to fallow.

Feed

Proper use of low pollution feed is the second critical component in minimizing environmental impacts. Aqua-Cage has been using high energy, low pollution feeds since 1983. Low pollution feed was not commercially available in 1983 so a custom formula was developed with Drs. Hilton and Slinger from the University of Guelph. The feed formula has changed almost yearly as new information becomes available and new manufacturing processes are developed by Martin Mills. Today low pollution feeds are available from all feed companies and almost universally used.

Early low pollution feeds simply minimized the indigestible portion of the diet, reducing solid waste, biochemical oxygen demand, and phosphorus. The second step in the evolution of low pollution feed was reducing phosphorus to the minimum level required for fish health and growth. The third development was new technology that allowed high levels of fat to be included. This increased the energy density of the feed which reduced the amount of feed needed to grow a unit of fish. Optimizing the protein to fat ratio took several years.

Recently it has become apparent that biochemical oxygen demand is the critical environmental waste product from cages. Current research involves further reductions of biochemical oxygen demand. Calculations indicate that biochemical oxygen demand, solid waste, and phosphorus produced per unit of fish have all been reduced 70-85% over the last 20 years through improved diets.

The other feed related source of waste is uneaten feed. Feed is expensive, accounting for 40% of production costs. Farmers have enormous economic incentive to waste as little as possible. New technologies, such as underwater video cameras, are further reducing feed waste.

Other Environmental Initiatives

Aqua-Cage has tried to be environmentally friendly when the opportunity arises. Two stroke out-board engines have been replaced by four stroke engines. "Green" hydraulic fluids are used. Most feed is purchased in bulk, eliminating tens of thousands of plastic bags per year. Only environmentally-friendly cleaners are used.

Other cage farms have their own environmental programs. Most feed used is a low pollution type. One farm has been working with a local University on biochemical oxygen demand and COD research. Another farm has installed a system which draws water from the bottom, aerates it and returns it to the bottom. Several farms are cooperating with Dr. C. Young Cho in developing waste production models. Most cage farmers think of themselves as pro-active environmentalists, stewards of the resource. Unfortunately the rare "bad apple" gets the publicity.

Sample Water Quality Results

Aqua-Cage hires Eco-North laboratories to take water samples around the farm. Phosphorus is consistently below 0.01 mg/L. Suspended solids are generally 0.25-1.0 mg/L. The highest suspended solids level ever recorded is 2 mg/L. Dissolved oxygen is generally 90% saturation or more, and always above 80% saturation. Two sample months are shown in Tables 1 and 2.

Table 1. Phosphorus and suspended solids data collected from various locations at Aqua-Cage Ltd. aquaculture farm.

Date	Site Location	Total Phosphorus (mg/L)	Total Suspended Solids (mg/L)
July 9 1998	Bay East	<0.01	<0.20
July 9 1998	Bay Centre	<0.01	<0.20
July 9 1998	Bay West	<0.01	<0.25
July 9 1998	Farm	<0.01	<0.50
Sept. 17 1998	Bay East	<0.01	0.75
Sept. 17 1998	Bay Centre	<0.01	2
Sept. 17 1998	Bay West	<0.01	0.25
Sept. 17 1998	Harbour East	<0.01	1
Sept. 17 1998	Harbour Control	<0.01	1
Sept. 17 1998	Harbour West	<0.01	1

Table 2. Temperature and dissolved oxygen data collected on October 13, 1998 from various locations around Aqua-Cage Ltd. aquaculture farm.

Location	Depth of Sample (m)	Temperature (° C)	Dissolved Oxygen (mg/L)
Bay West	0	15.6	12.2
Bay West	15	10	14.4
Bay Centre	0	14.1	11.9
Bay Centre	15	14.2	10.2
Bay East	0	13.9	10.4
Bay East	15	14.2	10
West Cage	0	14.1	9.9
West Cage	8	14.3	8.9
Centre-Surrounded by cages	0	14.2	9.1
Centre	8	14.3	9.2
Control-Stanley Island	0	14.3	10.4
Control	15	14.3	10
Control-3 mile point	15	14.3	10
Harbour West - downstream	0	14.1	9.4
Harbour West	8	14.1	8.9

Summary of Environmental Concerns Regarding Fish Farming

Water Quality

Fish farms add feces and small quantities of uneaten feed into the water. Zero tolerance pollutants, such as heavy metals, carcinogens, human pathogens, endocrine analogs, radioactivity, etc. are not produced. Potential negative impacts are limited to local eutrophication and reduction of local dissolved oxygen, especially in the hypolimnion. These impacts will only occur if these discharges are present in excessive amounts. Problems may be avoided by limiting inputs which in turn limits discharges. Limiting the feed used at a site is a very simple and effective way to limit input. The feed quota for a site will depend on the sites estimated carrying capacity. The quota can be adjusted up or down based on water testing results. An objective formula for this adjustment should be used rather than discretionary decisions. Accurately measuring a site's carrying capacity is impossible, so keep it simple, cheap, quick and conservative. Fine tune later with the quota adjustments. This system minimizes waste by providing the farmer with an incentive to grow the most fish possible on the feed quota.

Regulatory agencies should not be concerned with the internal workings of the farm, other than feed use, and water quality. The number of fish, size of fish, feed conversion, fish movements, etc. are irrelevant to the regulator. Requiring this information is an unreasonable intrusion.

Two other water quality questions that have arisen elsewhere concern therapeutant residues and antifouling compounds for nets. Studies done elsewhere indicate that therapeutants disappear quickly from the waste under farms, if they are ever present. Therapeutant use in Ontario is very low so it should not be a problem. Testing at several Ontario fish farms found no detectable therapeutant residues. Antifouling compounds are not used in Ontario on nets, to the best of the author's knowledge.

Water quality testing must be limited to parameters of concern, specifically phosphorus, dissolved oxygen, and suspended solids. Testing should be carried out periodically during the ice-free feeding period. Every 6-8 weeks is adequate providing the period following turnover is tested. Excessive testing is unwarranted and places an unreasonable financial burden on the farm. Testing must not become a farm funded government research project.

Introduction of Exotic Species

Fish farms should never be responsible for introduction of new species into any waters. Fisheries managers, baitfish, ornamental fish, and transportation cause more than enough introductions.

Fish should only be grown in waters where the species already exists in contiguous waters, or grown in a close system. The exception to this rule is where the introduction of the species would be considered desirable. Reintroducing a species into waters it previously occupied would be one example of a desirable introduction (e.g., sturgeon into many Ontario waters). Rainbow trout are obviously not a concern in the Great Lakes.

Genetic Dilutions of Native Fish

The gene pool of some populations of native fish should be protected where the original heritage gene pool still exists. The original gene pool is often lost as a result of heavy selective harvest, large scale stocking of the same species (especially but not exclusively from different stocks), habitat loss, remnant population isolation, government stocking, etc. Where a heritage gene pool exists, fish of the same species should not be cultured in the same waters unless they are kept in a closed system. Note that Ontario Ministry of Natural Resources has identified specific types of populations that need protecting, such as some sympatric and allopatric populations.

Protecting heritage gene pools also involves controlling all modifiers of the gene pool, not just fish farming. This includes selective harvest, habitat loss, government stocking, etc. Genetic concerns do not apply to introduced species. This is particularly true of rainbow trout since the Ontario Ministry of Natural Resources purchased its trout broodstock from the same hatchery that supplies farms with fingerlings.

Disease

Disease transmission from commercially farmed food fish to wild fish populations has never been documented, as far as this author knows. Ontario fish farms have an excellent fish health record. Some hatcheries have been certified specific pathogen free for about 25 years. Fish farms are highly unlikely to introduce new pathogens into the province because live fish or eggs are rarely imported. The few importations that do occur come from specific pathogen free sources in the Great Lakes basin (Quebec).

Within the province, farms are very careful to purchase only healthy fish. Ontario farmers have excellent professional fish health services provided by the Ontario Veterinarian College in Guelph which helps keep our fish healthy. The real risk of introducing diseases lies with other live fish movements. Farmers feel that management agencies are placing farms and wild fish at considerable risk by not regulating these other fish transfers, especially baitfish, but also ornamental and other food fish. Government programs are also often risky.

Regulatory Regime

Regulatory agencies, especially fisheries agencies, have consistently demonstrated an inability to deal with fish farms in a reasonable fashion, probably due to a total lack of understanding of what a fish farm is. Fish farming is NOT a fisheries activity, it is farming, feed lots producing meat for human consumption. Fisheries biologists have no more understanding of fish farming than wildlife biologists understand beef farming. Farmers of fish should not be dealing with fisheries biologists any more than a beef farmer should require permits from a wildlife biologist. Farmed fish are not a common property resource, they are private property and must not be subject to the whims of fisheries managers.

Most fisheries managers see little or no benefit to fish farming, so when a risk-benefit analysis is done even a very low risk is considered unacceptable because the perceived benefit is

negligible. Much greater risks associated with fisheries activities are considered reasonable because the perceived benefit, from a fisheries point of view, is much greater. A more objective observer would rate the farming benefits much higher, and the fisheries benefits much lower, than would a fisheries manager. Bait fish is a perfect example. Anglers releasing baitfish have caused hundreds, probably thousands of undesirable introductions in Ontario lakes (rock bass, perch, suckers, etc.) and spread parasites and pathogens. This proven, serious, and virtually uncontrolled problem is tolerated because it is part of sport fishing. Fish farming has not caused introductions or spread disease and yet is highly regulated and only semi-tolerated because it is not sport fishing. Note that the absence of the problems from farmed fish preceded the regulations. Fisheries agencies act as if their sole function is to provide recreational angling opportunities, not balanced resource management.

People seem unaware that fish farms may have beneficial effects. They always increase local fish populations, creating angling opportunities. Interestingly, the most successful (perhaps the only successful) lake trout rehabilitation in the Great Lakes, outside Lake Superior, has occurred in the waters around Aqua-Cage Fisheries during the time Aqua-Cage has been operating. This may be a result of habitat improvement caused by the farm.

Fish farming is more regulated than most activities. A cage farm in Ontario requires the following:

1. fish culture license from Ontario Ministry of Natural Resources;
2. water lot tenure from Ontario Ministry of Natural Resources;
3. exemption to moor in navigable waters from Federal Department of Transport;
4. various licenses and permits from local governments which may include fish culture and environmental permits from First Nations, building permits, zoning variances, etc. (generally local permits require public hearings);
5. Hazard Analysis Critical Control Point (HACCP) standards through the independent "Healthy Salmon Program"; and
6. regulation of therapeutant and chemical use (prescriptions or permits may be required).

Farms previously required Certificate of Approval's from the Ontario Ministry of Environment. This requirement was discontinued with no input from industry. Ontario Ministry of Environment subsequently refused to set standards or become involved with regulating cage farms, despite years of lobbying by industry and the Ontario Ministry of Agriculture and Food. Environmental standards are now included in the Ontario Ministry of Natural Resources fish culture license.

Permits were previously required to ship live fish. This has been replaced by requiring normal commercial documentation (i.e., bill of lading).

The inputs and outputs of the farm are also highly regulated. Fingerlings are purchased from hatcheries which have the same requirements as a cage farm plus the Ontario Ministry of Environment Certificate of Approval and often a Department of Fisheries and Oceans Fish Health Certificate. Processing plants are subject to federal and provincial inspection. They document for both Quality Management Programs (QMP) and increasingly, HACCP. Feed manufacturing also involves tight regulatory controls.

Big brother watches from cradle to grave.

Reasonable regulations must place fish farming in the context of the real world, which is not a pristine place. Virtually all of the dominant coldwater species in the Great Lakes are introduced, from zooplankton through forage fish to the top predators. There is no natural coldwater ecosystem to preserve so don't pretend there is. Managers should be considering the needs of all users of the resource, not just anglers, and the benefits to society as a whole. Objectively, fish farming can be one of the most environmentally friendly activities we humans can undertake.

Regulations should be effective in dealing with an issue. This means the regulations must apply to all potential sources of the problem, not one sector. The potential negative impacts of fish farming are concerned with fish waste and the movement of live fish. Fish pathogens, as an example, may be spread by the movement of any live fish. Note that fish pathogens will affect most species. Baitfish can carry salmon diseases. Introduction of pathogens has been documented via baitfish, government stocking, and transportation (shipping, canals, etc.). Pathogens spreading from commercially farmed food fish to wild fish has not been documented. Regulating only the low risk vector (i.e., farms), and ignoring high risk vectors is ineffective and absurd, but that is the situation under both Ontario regulations and Canadian Federal regulations. Regulate by problem not by sector. Special rules for fish farms are NOT required.

A wise man said that dairy farms operating under the same constraints as fish farms would be required to milk moose.

Appendix 13

Environmental Assessment Tool for Private Aquaculture in the Great Lakes Basin: Summary of a WORKING DRAFT

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Introduction

An increasing interest in aquaculture development in the Great Lakes region has prompted the Great Lakes Fishery Commission's Council of Lake committees (CLC) to seek development of a model management program for private aquaculture. Towards this goal, Professor Anne Kapuscinski and her graduate student, Deborah Brister, are developing an aquaculture environmental assessment tool that is user-friendly, interactive, and addresses lake-based, land-based, and secured aquaculture systems.

Environmental Assessment Tool

The Environmental Assessment Tool will include three interrelated components to guide case-specific review of each aquaculture operation. First, a computerized **Assessment Pathway** guides the user through assessment of potential environmental effects. The user answers a series of carefully worded questions about the species (including genetic strains) and the accessible aquatic ecosystem, identifying whether or not the aquaculture operation under review poses any specific risks. Should any risks be identified, the user is led to consider risk management measures, including culture methods, facilities design and operations management. This would include whether or not measures capable of managing the identified risk currently exist. Second, the **Supporting Text** provides: scientific background, including citations of relevant documents, for the questions and alternative decisions in the assessment pathway; **more detailed risk management recommendations**; a glossary of scientific terms; and other relevant appendices. Third, the **Summary Documentation** automatically traces the user's path through the computerized Assessment Pathway and prompts the user to describe the rationale for any selected risk management measures. The Summary Documentation provides transparent documentation of the assessment process, thus helping to keep aquaculturists, government regulators, and interested citizens equally informed and to reduce conflict in some cases.

Overview of Environmental Assessment Tool

Determination of Assessment Pathway

The pathway is determined by questions that ask: type of organisms to be cultured (fish, shellfish or plant), collection and/or growout methods of organisms, and location (Great Lakes-based or land-based facilities). Lakes-based projects involving species other than those that are indigenous or naturalized in the Great Lakes will be directed to consult with relevant agencies, according to the Introductions in the Great Lakes Basin Procedures for Consultation (Council of Lake Committees 1992), before proceeding further. Below is an overview of one of the pathways in the environmental assessment tool.

Assessment of Great Lakes-based Aquaculture Systems

Assessment of Suitable Environment

These questions assist the user in identifying whether an organism can survive and thrive in the surrounding aquatic ecosystem. The structural integrity of the facility is also considered here. Important factors include temperature, pH, degree of ice cover, wave heights, and currents (Beveridge 1996). Additional factors are considered in later assessments.

Genetic Effects

These questions assist the user in identifying whether an organism has been genetically engineered (deliberate gene changes, deliberate chromosomal manipulations or interspecific hybridization). Projects involving genetically engineered organisms are directed to the Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms (Scientists' Working Group on Biosafety 1998). This manual is appropriate for assessing commercial-scale aquaculture of genetically engineered animals or plants. It is an expanded version of the Performance Standards for Safely Conducting Research with Genetically Modified Fish and Shellfish (ABRAC 1995). Questions will also assist the user in assessing effects on the genetic makeup and fitness of wild populations due to interbreeding with escaped aquaculture organisms derived from non-local genetic sources. The user is asked about known genetically distinct populations, sources of cultured organisms, and feasibility of sterilizing cultured organisms.

Disease Effects

These questions assist the user in identifying whether the cultured organisms have been certified to be free of emergency or restricted pathogens. If cultured organisms are salmonids, the user is instructed to evaluate the broodstock or production stock with the Great Lakes Fish Disease Control Policy and Model Program (Hnath 1993). The user is also asked if emergency or restricted pathogens have been identified in wild fish populations in surrounding waters. These questions aim to minimize the possibility of spreading disease to cultured fish and further contaminating wild fish.

Impacts on Recovery or Rehabilitation Plans

These questions assist the user in identifying whether the cultured organisms or the facility could harm any listed Endangered, Threatened, Special Concern, or Vulnerable species. The user is asked to identify species at risk and determine, with the assistance of the appropriate government agency, whether the cultured organism or the facility may adversely affect the species at risk. Questions also prompt the user to consider other recovery or rehabilitation plans that may be affected, e.g., recovery of wild lake sturgeon in Lake Ontario (Orsatti et al. 1998).

Impacts on Areas of Concern

These questions assist the user in identifying whether the cultured organisms or the facility could harm Areas of Concern designated by the International Joint Commission. Clean-up and restoration plans have been identified in 42 areas of the Great Lakes (International Joint Commission 1987). The user is asked to determine proximity to Areas of Concern and possible effects on any recovery plans that include fish and wildlife rehabilitation, improvement of degraded benthos, or remediation of eutrophication or undesirable algae.

Effects of Settleable Solids on Benthos and Shellfish

These questions assist the user in identifying whether the cultured organisms or the facility could adversely affect benthic species or shellfish beds. Excessive wastes from culture facilities may cause smothering of benthic environments, a buildup of contaminants within the sediments, promote a higher level of resistant bacteria, change sediment chemistry, deplete oxygen levels, and cause a shift in community structure of benthic species (Weston 1990; Gowen et al. 1994; Silvert 1994; Sowles et al. 1994; Beveridge 1996). Shellfish also may be vulnerable to contaminants and smothering. The user will be asked questions that help identify vulnerable benthic areas and significant shellfish beds. This section will also ask questions about the aquaculture facility's potential exposure to fouling agents (e.g., zebra mussels).

Impacts on Breeding Areas, Nurseries, and Fish-eating Animals

These questions assist the user in identifying whether the cultured organisms or the facility could harm breeding or nursery areas of wild organisms. Proximity to these areas will be the most important issue. The user is asked questions that will assist in identifying areas that are vulnerable. Questions also consider effects on fish-eating mammals and birds.

Cumulative Impacts due to Proximity to other Aquaculture Facilities

These questions assist the user in identifying whether the culture operation could adversely affect wild populations and pre-existing aquaculture operations through a higher cumulative waste load that could decrease dissolved oxygen levels and increase dissolved nutrients, thus promoting eutrophication. The objective of these questions is to assess cumulative impacts.

Impacts of Facility and Infrastructure

These questions assist the user in identifying whether the facility or its related infrastructure (e.g., construction of additional buildings or roads) could harm habitats for species at risk, or fisheries and wildlife restoration/rehabilitation projects listed in the Lake Community Objectives. Users are directed to suggested agencies to make these determinations.

Effects on Other Lake Users

These questions assist the user in identifying whether the facility or its related infrastructure are located in areas that may affect other lake users. Potential impacts on culturally, historically or navigationally sensitive sites are also considered. Users are prompted to refer to suggested agencies to make these determinations.

Risk Management Measures

This section helps the user to develop feasible ways of reducing or preventing specific environmental problems identified in the above assessments. Measures could also include the development of an emergency response plan, a fish disposal plan, and a fish-eating predator prevention plan.

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